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POST-WAR BUILDING STUDIES

NO. I

HOUSE CONSTRUCTION

BY

AN INTERDEPARTMENTAL COMMITTEE
APPOINTED BY
THE MINISTER OF HEALTH
THE SECRETARY OF STATE FOR SCOTLAND
&
THE MINISTER OF WORKS



LONDON: 1944
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POST-WAR BUILDING STUDIES

The series of Reports being published under the title of Post-War Building Studies owes its origin to a desire expressed by professional and other institutions connected with the building and civil engineering industries to assist and support the Ministry of Works in regard to post-war plans. During the latter part of 1941 the then Minister, in order to take advantage of these offers of assistance which he was receiving from all quarters, encouraged the establishment of a series of Committees to investigate and report on the major problems which were likely to affect peace-time building. He also offered, on behalf of the Ministry, to provide the necessary staff and organisation to co-ordinate the various inquiries, in such a way as to avoid duplication of effort and to secure so far as possible uniform direction and policy.

A full list of the Reports which are being issued is given on the back page of the cover.

The Committees for the most part were either appointed by a Government Department or convened by a professional institution, a research association or a trade federation, as seemed most appropriate in each case; they were so constituted as to ensure that the Reports contain the considered views of experts and others closely concerned with the subject. The Minister gratefully acknowledges the work of the Committees and the valuable assistance given both by the various convening bodies and by the individual members.

The Committee on House Construction, whose report appears first in the series, was appointed in September 1942, at the suggestion of the Minister of Works, by the Minister of Health, the Secretary of State for Scotland and the Minister of Works jointly. After the submission of this Report the Committee was reconstituted on a broader basis as a standing advisory committee representative of the professions of architecture and engineering and of all elements of the building industry.

The Reports in this series are not official publications in the sense that the Government as such is responsible for or necessarily accepts the views expressed, but their contents are authoritative and cannot but be of great value to all concerned with preparations for building after the war.

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1944

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HOUSE CONSTRUCTION

To THE RIGHT HONOURABLE HENRY URMSTON WILLINK, M.C., K.C., M.P., MINISTER OF HEALTH;

THE RIGHT HONOURABLE THOMAS JOHNSTON, M.P., SECRETARY OF STATE FOR SCOTLAND; AND

THE RIGHT HONOURABLE LORD PORTAL, D.S.O., M.V.O., MINISTER OF WORKS.

SIRS, We were appointed in September, 1942, "to consider materials and methods of construction suitable for the building of houses and flats, having regard to efficiency, economy and speed of erection, and to make recommendations for post-war practice in the light of all relevant findings of the Study Committees co-ordinated by the Directorate of Post-War Building of the Ministry of Works." We now have the honour to present our Report.

Fifteen full meetings of the Committee have been held. After considering our terms of reference in relation to the problems which will face the building industry at the end of the war, we decided on the following programme of work:

1. To investigate the alternative methods of house construction used in inter-war years, and to advise on such methods as may be capable of application or suitable for development in the post-war period.
2. To consider the application of methods of prefabrication to house building.
3. To examine any proposals placed before us for new methods of construction.
4. To consider proposals made by the Study Committees of the Directorate of Post-War Building, Ministry of Works, in their relation to house construction.
5. To make recommendations for the carrying out or testing of forms of construction by field research or experiment.

The first stage of our work—the survey on inter-war methods of construction—is now complete, and gives occasion for this report; the survey covers house construction only as this seemed the most urgent. Flat construction was reviewed by the Ministry of Health's Departmental Committee on Construction of Flats for the Working Classes as recently as 1937, and we intend later to bring this study up-to-date.

We are not yet prepared to express any opinion on prefabrication except in so far as it is already advantageously applied in the building industry to many standardised units used in house construction. Proposals for new methods of construction, claiming to be particularly suitable for prefabrication, have been submitted to the Committee. Among them none call for special comment at this stage. We would note, however, that the term is too frequently applied to the manufacture of the entire house and its rapid and mechanical erection on the site, rather than to the application of factory methods in the mass production of certain component parts, thereby reducing site costs. The subject of prefabrication is being considered in principle by the Prefabrication Section of the Standards Committee of the Ministry of Works.

We have appointed a Technical Sub-Committee to undertake the preliminary examination of schemes and projects for submission to the Committee. A number of new methods of construction have been submitted to date, the degree of promise and accomplishment varying very greatly. We have been able to offer advice and assistance in promising instances, and wish to take the opportunity allowed by the publication of this Report to make known the services which are available to promoters of new methods.

The Minister of Works has recently appointed a Controller of Experimental Building Development who will arrange, in consultation with the Committee, to give all assistance towards the carrying out of full-scale experiments and demonstrations where necessary. The Controller is responsible for the co-ordination of experimental building work, for the licensing of the necessary materials, and for the inspection of such work in the field. He will also secure the collaboration of other manufacturers or technicians wherever this may be required. Furthermore, the services of the Building Research Station at Garston, Watford, Herts., have been put at the disposal of the Committee in connexion with the examination of schemes. Schemes should be submitted to the Secretary, Inter-Departmental Committee on House Construction, Ministry of Works, Lambeth Bridge House, London, S.E. 1.

Facilities have been made available to allow of the early undertaking of a co-ordinated and controlled experimental programme by the appointment of the Controller of Experimental Building Development. The Building Research Station has given us an opportunity of commenting on a programme of research involving short- and long-term experimental work, which we have commended for consideration. It incorporates proposals resulting from our investigation, as well as from those made by the various Study Committees of the Post-War Building Directorate. Much help can be given by the different interested industries in fostering new development, and we hope it may be possible to count on their full collaboration. Our time in future will be very largely devoted to the framing of recommendations in the light of further studies for the adoption of various methods of house construction after the war.

In Scotland the Scottish Special Housing Association was set up in 1937 specially to erect houses by alternative methods of construction, and in terms of Section 2 of the Housing (Financial Provisions) (Scotland) Act, 1938, is the Association "approved by the Secretary of State to provide new houses for experimental or demonstration purposes" with the aid of subsidies under that Act. The Association, therefore, is in a position to carry out experiments in housebuilding and to provide the necessary co-ordination and supervision of such experiments. We hope that the fullest advantage will be taken of the wide experience of this body in carrying out a programme of experimental housebuilding in Scotland.

The development of new methods of construction after the last war was hampered in some districts in England by the operation of restrictive building by-laws, and the Minister of Health found it necessary on occasion to exercise his powers under the Housing Acts to relax such by-laws. Similar difficulties should not recur with any reasonable form of building, since practically all building by-laws have been brought up-to-date under the provisions of the Public Health Act, 1936, and follow the model series issued by the Ministry after the passing of the Act. No corresponding difficulties have arisen in Scotland.

Having regard to the possibility that in the immediate post-war period it will not be possible to build brick houses to the total number required, we have recognised the extreme urgency of the situation and of the need to report at an early date on such alternative methods as are immediately available and can be considered satisfactory for post-war use. Much can be learnt from experience gained with alternative methods used during the inter-war period. No extensive survey of these special methods had been made before, and we felt it essential to study them and put on record the lessons to be drawn from them; obviously, methods

which have stood the test of time can be proposed with more confidence for use than new and untried methods. We visited Scotland in order to inspect a number of the constructions.

Our investigations in connexion with the survey led us to make recommendations in respect of standards of performance for use and guidance in the development of alternative methods; we have therefore submitted suggestions in connexion with basic technical considerations for house construction.

We requested the Building Research Station to supply information on materials likely to be associated with the development of new forms of construction and such as might assist in the attainment of the suggested standards, having regard to a possible temporary shortage of certain conventional materials as a result of the war. It was thought that the publication of these notes would serve a useful purpose. We have therefore framed our report to include:

Part I. Suggested basic technical considerations of house construction (p. 7).

Part II. Survey of alternative forms of construction used in the inter-war period 1919-39 (p. 42).

Part III. Notes on materials (p. 93).

A summary of the Report and the conclusions are given on p. 137.

For the subject matter of this Report, we are indebted primarily to the Building Research Station. The survey of inter-war methods was carried out by them, and our thanks are due to those officers of local authorities and firms who assisted them in the investigation. We also received valuable information from the officers of the Scottish Special Housing Association. The *Recommendations for the Use of No-fines Concrete* (see Appendix, p. 140) were drawn up with the help of the Cement and Concrete Association. We wish to thank both organisations for the valuable assistance given. Finally, we wish to express our thanks to our Secretary, Miss J. G. Ledeboer, for the admirable assistance given in our work.

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HOUSE CONSTRUCTION

REPORT BY AN INTERDEPARTMENTAL COMMITTEE APPOINTED BY THE MINISTER OF HEALTH, THE SECRETARY OF STATE FOR SCOTLAND, AND THE MINISTER OF WORKS

PART I. SUGGESTED BASIC TECHNICAL CONSIDERATIONS OF HOUSE CONSTRUCTION

1. The technical problems to be faced in executing, after the war, the proposed building programme of $3\frac{1}{2}$ to $4\frac{1}{2}$ million houses in ten years differ, in degree rather than in kind, from those faced by the building industry after the war of 1914-18. After the last war the building industry was seriously affected by shortages of skilled labour and essential materials; at the same time there was an acute housing shortage. A number of new methods of construction were evolved in an attempt to ease the situation; the Tudor Walters Report, 1919, first called attention to the need to supplement traditional methods with newer forms and this development was encouraged by two Committees of the Ministry of Health on new methods of construction, which reported in 1920 and 1924.

2. Of the total of $4\frac{1}{2}$ million houses erected in Great Britain between 1919 and 1939, the number of houses built by new methods was small. There was a reversion to brick construction wherever the supply of labour adjusted itself to building demands; this took place only very slowly in some areas, and not always entirely. In Scotland the need for the use of alternative methods was more acute, and was recognised by the formation of the Scottish Special Housing Association in 1937 with powers to assist local authorities in their housing programmes by the building of houses by special methods of construction.

3. A situation comparable to that experienced in 1919 is likely to occur after this war; there can hardly fail to be an even greater demand for the rapid construction of new dwellings. To an extent the position may be easier owing to the retention during the present war of some portion of the building industry personnel in civil employment and to the steps being taken towards securing a balanced industry in the after-war years. The problem of the production of materials is not likely to be so formidable as that of the supply of trained building operatives. Attention will have to be directed to supplementing conventional building operations by the use of methods of construction which will employ labour as yet unskilled in building. In particular, full co-operation between the building and the engineering trades will be essential.

4. In assessing the merits of alternative forms of construction, the first consideration is what constitutes a proper standard of habitability. The second must be the extent to which alternative forms avoid calls on normal building labour or material. To judge the technical efficiency of a system some standard of comparison is necessary; a natural standard is the conventional brick house so well established in public confidence by traditional use. For reasons which will be mentioned later, the brick house does not in all respects provide a suitable standard of comparison. It would clearly be unreasonable to criticise an alternative form simply because in strength and stability it is not the equal of the brick house, the walls of which are thicker than they need be for mere strength and stability in order to provide against moisture penetration and heat loss. Again, we had to consider at the outset whether the 9-in. solid wall or the 11-in. cavity wall should be taken as the standard construction. It was decided to adopt the latter because of the extent to which practice had changed from 9-in. solid brickwork to 11-in. cavity wall, having regard to frequent failures of the 9-in. wall to prevent damp penetration.

5. During the course of the survey of inter-war methods it became clear that the standard adopted, adequate perhaps for an historical survey, was inadequate for and might prejudice future developments. There had been no occasion to define in precise scientific terms what was required of a traditional brick house, because age-long experience and practice had alone been sufficient. But it was not possible, for two reasons, to consider alternative forms without more precise connotation of basic requirements; the new forms could only be assessed on the basis of an agreed set of standards of performance.

6. In the first place, the survey of methods of alternative construction used in the inter-war period revealed that failure in a number of systems was due to a lack of set values at the time of building; some gaps in the knowledge at that time have now been bridged. Considerable research has been carried out, much of which has been assembled by various Post-War Building Study Committees appointed at the instance of the Ministry of Works. The reports of these Committees so far presented are provisional, and are liable to be modified by further consideration. The usefulness of this report would, however, be very circumscribed, if it took no account of the work so far done by these Committees, and we owe it largely to discussions on these Committees, that we have found it possible to make suggestions for standards which are not tied to conventional constructions.

7. In the second place, as a result of the submission to the Committee of a number of new methods of construction, we have had to recognise that some of the proposals show ignorance of first principles in house construction, whereas others attempt to achieve new values, there being no body of common knowledge to guide development. The full co-operation of the professions affected and of industry generally will be essential in producing a range of alternative designs suited to post-war conditions. In order that they may be in a position to apply themselves most usefully to the design of improved forms of construction, it is desirable that clear guidance should be given on basic design requirements for future housing embodying the improvements in standards that are now being considered. The opportunity to make these improvements while new forms are developing must not be lost.

8. This has led us to put forward in this Report suggestions as to what these standards might be. It will be seen that these desired standards vary considerably from the values realised by the conventional brick and timber house. They are, however, tentative, and may require revision in the light of experience. We recognise that it may not always be possible to achieve every one of them, having regard to cost and other considerations. It might be thought that some of the standards have been set rather high, but we are of opinion that where new methods are applied it will not be difficult, nor necessarily more costly, to attain these high standards provided good use is made of the variety of materials likely to be available to promoters of new constructional systems. Consideration of post-war house construction cannot be divorced from questions of cost. Great care will be needed in the selection of materials and methods of construction to secure the standards suggested and at the same time to avoid increasing costs unnecessarily. With this in view, we welcome the appointment by the Minister of Works of a Building Costs Research Officer.

9. The basic technical considerations which chiefly affect the consumption of labour and materials in house construction are:

Strength and stability;
Moisture penetration and condensation;
Thermal insulation;
Sound insulation;
Fire hazard;
Maintenance and durability;
Vermin infestation

10. In the following pages these basic considerations will be reviewed and, where possible, precise numerical design requirements will be given together with some indication as to how the standards may be achieved.

11. The problems have been examined generally in terms of one- or two-storey dwellings, though there is occasional reference to flats.

STRENGTH AND STABILITY

ASSUMPTIONS FOR LOADING IN THE DESIGN OF DWELLINGS

12. The following recommendations for design assumptions for loading follow a study which has been made for the Codes of Practice Committee for Civil Engineering, Public Works, Building and Construction Work. They have not yet been adopted by the Codes of Practice Committee.

13. The figures now suggested for wind loads are based on extensive research carried out at the National Physical Laboratory for the Wind Pressures Committee of the Building Research Board, Department of Scientific and Industrial Research. This work establishes loadings which are related to actual conditions as determined by careful experiment. Doubt has been expressed as to the validity of the results of wind-tunnel experiments, and reference made to the fact that buildings have stood up for many years, although constructed in ignorance of the above-mentioned research. The reply to this is surely that it is more economical to use precise scientific data rather than introduce an unknown factor of safety which is frequently unnecessarily high and therefore uneconomic.

The problem of the wind loading of buildings is properly one of aerodynamics, and the actual pressures obtained depend on the nature of the air flow over and around buildings, and, in particular, effects of shelter by neighbouring buildings is especially important. The difference between normally exposed and fully exposed sites is dealt with in the rules which follow.

DEAD LOADS

14. The dead load comprises the weight of all walls, floors, partitions, roofs and all other permanent construction in the building. The unit weights of the various materials are given in *British Standard* 648–1935.

SUPERIMPOSED FLOOR LOADS

15. Superimposed floor loads comprise all floor loads other than dead loads. Floors for houses of not more than two storeys should be capable of supporting a superimposed floor load of 30 lb. per sq. ft. or a load of 240 lb. uniformly distributed on any foot width of slab or floorboard, whichever gives the worse conditions. Beams should be capable of carrying a load of 1920 lb. uniformly distributed. *Note*: Beams, ribs and joists spaced not more than 3 ft. apart may be calculated for slab loading.

PARAPETS AND BALUSTRADES

16. Parapets and balustrades should be designed for a horizontal load of 25 lb. per foot run acting at handrail or coping level.

WIND ON VERTICAL SURFACES

17. The horizontal wind load acting on the vertical surfaces of a building not more than 20 ft. high to eaves should normally be assumed to be 8 lb. per sq. ft., but in the case of buildings situated in especially exposed situations (at the seaside, on the shores of lakes and estuaries, on open moorlands or hill-tops, etc.), the load should be assumed to be 16 lb. per sq. ft. One half of wind load may be assumed to act as a pressure on the windward face, and one half as a suction on the leeward face.

18. In the case of dwellings of normal proportions, where the height does not exceed three times the width, and where the building is stiffened by walls or built-in panels of brickwork or concrete and with cross walls of similar material, it will not be necessary to make calculations for the general stability of the building against wind pressure. For calculation of the stability of external walls, panel fillings and their supports 70 per cent. of the above wind load should be considered to be acting in either direction (inwards or outwards) on all external faces of the building.

ROOF LOADING

19. The superimposed snow and wind loading to be taken for roofs are given in paragraphs 20 and 21.

20. *Flat roofs.* On flat roofs and on roofs up to 10° pitch a superimposed load (including snow) of 30 lb. per sq. ft. measured on plan. In the case of flat roofs of light construction, which may be affected by suction, a negative pressure (suction) of 10 lb. per sq. ft. should be assumed to act over the whole area of the roof.

21. *Sloping roofs.*

i. A snow load of 10 lb. per sq. ft. measured on plan.

ii. A negative pressure (suction) on the leeward slope of 8 or 16 lb. per sq. ft. normal to surface. (See para. 17.)

22. Sloping roofs should be capable or resisting the above conditions, (i) and (ii) singly, or in conjunction.

23. The roof covering, if it can be walked on, and the individual members of the roof framing, should be capable of sustaining the following alternative loads:

100 lb. concentrated at any point accessible by means of a ladder.

200 lb. concentrated at any point accessible without a ladder.

MOISTURE PENETRATION AND CONDENSATION

24. Dampness in houses may be due to rain penetration through external walls, the rise of moisture through walls or ground floors, rain or snow penetration through roofs, or to internal condensation. In the following notes each of these sources of dampness is examined in turn.

25. Rain penetration through external walls is considered in terms of selected types of wall which have been commonly used in the past, but the principles have wider application and can be used in assessing the degree and extent to which damp will penetrate new forms of wall construction.

DAMP PENETRATION THROUGH EXTERNAL WALLS

I. SOLID WALLS

A. COMPOSED OF SMALL UNITS BONDED IN MORTAR

26. Water in liquid or vapour state will permeate most types of brick and stone and all the usual types of mortar. In any wall composed of these materials, therefore, there are three possible ways in which moisture can enter—through the units, through the mortar joints, or through cracks between the units and the joints. Water is drawn through such materials and cracks by capillary attraction. As this capillary force may be supplemented by wind pressure on the face of the wall, exposure is a factor which influences moisture penetration.

27. In practice, serious penetration is seldom due to the permeability of the unit or of the mortar; it usually occurs through fine cracks between the units and mortar. These cracks are caused by the shrinkage of the mortar as it dries, by poor adhesion, or by the inevitable slight settlements to which every building is subject. The physical characteristics of the walling unit and the mortar have an important influence on the extent of penetration at such cracks. If the walling material is absorbent, water falling upon it will be temporarily held and subsequently dried out by evaporation; but if that material is non-absorbent all the water will run down the surface till it encounters a crack into which it may be drawn or blown in considerable quantities and so pass directly to the inside face.

28. Before the materials for a solid wall are specified, the designer should be clear as to how he intends to keep out damp. The alternatives with this form of construction are either to use a relatively impermeable and unabsorbent unit, laid in a mortar with the same characteristics, thus producing a "barrier" to water; or to use an absorbent unit, in an absorbent mortar, which will act as a "sponge," holding the water till weather conditions enable it to be evaporated.

29. The first method has certain inherent difficulties, besides demanding a very high standard of workmanship if it is to be successful. The chief difficulty is to obtain a suitable mortar, as the characteristics which are required (density, impermeability, freedom from drying shrinkage, good adhesion and workability) are incompatible; any hair cracks in the wall surface are likely to lead to serious penetration.

30. The second method does not demand such careful workmanship and there is no difficulty in obtaining a mortar of absorbent qualities, but if rain is driven against a solid wall of this type for a long enough time moisture must eventually reach the inner face of the wall. If the rain stops before this happens and a period of drying weather follows, the moisture will be evaporated and no signs of damp will appear on the inside; but prolonged rain or an exposed site will reveal the weakness of this type of wall.

31. Moisture will penetrate solid walls of concrete bricks or blocks in the same way as it penetrates brick walls, but there is an additional risk of cracks between the mortar and the units unless the blocks have been thoroughly cured before use, so that drying shrinkage is reduced to a minimum.

32. It is concluded that a solid wall of small units bedded in mortar cannot be relied upon to exclude damp, and for this reason the 9-in. solid brick wall is unacceptable as a standard for small house construction. As already indicated, the trend of practice in recent years has been towards the 11-in. cavity wall.

B. COMPOSED OF SMALL UNITS BONDED IN MORTAR AND FACED EXTERNALLY

33. External facings or skins have been used in many forms, for aesthetic or waterproofing reasons. Facings of natural and cast stone, faience and terra-cotta will probably not be used to any extent in small house work, but others, such as renderings, brush-applied finishes, and tile or slate hangings have been largely used on cottage work in many parts of the country.

34. A few general points are worth attention:

a. If the object of the treatment is to provide an impermeable barrier, the facing must be continuous over the whole surface of the wall, with no cracks. The reason for this has already been explained in para. 26ff. above; if a wall is of unabsorbent material there will be a cumulative flow of water down the face, and the chance of damp penetration through any crack in the face is greater than in the case of a wall of absorbent material with similar cracks. If water does penetrate behind the impermeable facing the wall is likely to remain damp for a long time, as the nature of the facing will prevent evaporation.

b. If the facing is non-absorbent and is not continuous over the whole wall area (*e.g.* tile-hanging to the first floor only, with brick below) provision should be made for throwing the water from the non-absorbent surface clear of the wall below. It is a matter of common observation that as the result of the large flow of water from non-absorbent surfaces penetration is often greatest immediately below areas of tile-hanging or rendering or large windows with ineffective sills.

c. Renderings are dealt with later in the section on Durability (p. 33). It is enough here to point out that renderings can reduce moisture penetration in two distinct ways, as does a solid wall—*i.e.* by acting as "barriers" or as "sponges." Before any rendering is specified it should be decided which principle is being relied upon. The practical difficulty of obtaining an impermeable rendering free of cracks is tending to increase the use of the more open-textured absorbent type of rendering.

d. The brush-applied coverings, such as slurries, washes, external paints, distempers, and emulsions all require periodic renewal.

C. SOLID MONOLITHIC CONCRETE WALLS

35. Reinforced concrete is most commonly used in this type of walling. With careful specification and workmanship it is possible to obtain an impermeable concrete, but three points need careful attention when this material is used for walling. These are the construction joints, the expansion joints, and shrinkage cracking. The joints can be made weathertight by care in their detail design, in their location, and in execution; shrinkage cracking can be controlled by adequate reinforcement.

36. Two other forms of monolithic concrete wall should be noted. Thin dense concrete walls have been successfully used as the outer leaf of cavity walls for small houses, these walls being lightly reinforced to control shrinkage cracking. The principle upon which the resistance to moisture penetration of these walls is based is that of the cavity wall.

37. Solid concrete walls of no-fines concrete have also been used for small house construction. This concrete is mixed with an aggregate from which all the fine stuff has been removed. Owing to the structure of the concrete, transference of moisture by capillary attraction cannot take place. With an external rendering, to prevent wind pressure forcing water through the wall, this type of concrete is highly resistant to moisture penetration.

II. WALLS COMPOSED OF HOLLOW UNITS BONDED WITH MORTAR

38. Hollow blocks of clay or concrete have been widely used for walling abroad, but so far they have not been extensively used in this country. Resistance to penetration depends mainly on the treatment of the joints, and many attempts have been made to improve this feature; one of the more recent consists of shaping the block during manufacture so that mortar can be excluded from one part of the joint, thus breaking the capillary path.

III. CAVITY WALLS

39. The principle upon which the cavity wall depends for the exclusion of water is that of interrupting the capillary path by an air space within the thickness of the wall. If the cavity is continuous and there is no "bridge" of solid material capable of transmitting water across the cavity, this form of construction provides a complete safeguard against moisture penetration.

40. In practice, the cavity may have to be broken at such points as lintels, sills and jambs, and by the use of wall ties. Careful design of detail at these points and careful workmanship are needed if moisture penetration is to be avoided. The pattern of wall tie used is important; all the common patterns incorporate some feature to prevent moisture trickling across them, but they vary considerably in the area they present for the retention of mortar droppings, which are a common path for moisture penetration.

41. The difficulty of keeping the cavity free from droppings has sometimes led to the practice of completely filling the cavity. Waterproofed cement mortar, fine concrete or bituminous preparations have been used on the assumption that a continuous impermeable membrane would be formed; but there are serious objections to the use of mortar or concrete in this way. While a concrete mix can be obtained which is impermeable, it is impossible to obtain the high standard of workmanship which is necessary in its placing and consolidation in a narrow cavity; the resulting thin layer of dense concrete will shrink and crack, thus producing a clear path for the transmission of water from one leaf to the other. It is considered that the filled cavity will not be as efficient as the true cavity.

42. Whether a cavity should be ventilated or not has frequently been a matter for discussion. The chief argument in favour of ventilation is that a good current of air in the cavity keeps the internal leaf of the wall dry and so prevents the decay of timber built into the wall. A fair criticism of this claim is that with proper constructional details the inside leaf does not get sufficiently wet to give rise to internal dampness and that timbers built into the wall will never reach the 20 per cent. moisture content necessary to permit the growth of wood-destroying fungi. It should be realised that even though the ends of timber get damp the moisture will rapidly move inwards and will evaporate from the surfaces exposed inside the house. Only when there is a definite source of moisture penetration will timbers become and remain sufficiently wet for the support of fungoid growth.

43. The advantage of sealing a cavity is definite: the heat loss through an unventilated cavity wall is less than through one that is fully ventilated. The heating "requirements" of the house are therefore lower and the risk of condensation on the internal surfaces of the wall is reduced.

44. A comparison of the heat transmittance coefficients U (=B.Th.U. per sq. ft. per hr. for 1° F. difference of air temperature) for ventilated and unventilated 11-in. cavity walls is made in the following table.

WALL	SOUTH EXPOSURE SEVERE	NORTH EXPOSURE SEVERE	N.E. AND N.W. EXPOSURE NORMAL
11-in. cavity wall, plastered, unventilated	·29	·31	·30
11-in. cavity wall, plastered, ventilated	·33	·36	·34

45. The lower heat loss through the unventilated wall on the cold side of the house might well be sufficient to obviate condensation of which there is a serious risk with a ventilated wall.

IV. WALLS FACED WITH IMPERMEABLE SHEET MATERIALS

46. An example of the use of impermeable sheet materials for walling is the "steel-clad" houses built in the inter-war period. From the nature of the materials, the only ways by which moisture will be able to penetrate are through the joints, or through cracks between a jointing material and the units. As has been stressed in connexion with relatively impermeable materials, lack of absorptive capacity in a walling material increases the likelihood of penetration at joints and cracks by reason of the flow of water down the surface of the wall. This will be increased in the case of completely impermeable materials like metals. The design of the joints between impermeable sheets is, therefore, of great importance. So far they have fallen into two classes—those in which there is not intimate contact between adjacent units (the traditional lapped joint, for example) and those in which the units are "butted" in some way and the joints filled. In the case of lapped joints there is little danger of capillary attraction, but the joints must be protected against penetration by wind-driven rain. In the case of "butted" joints there is some difficulty in obtaining a jointing material that will not only make a watertight joint in the first place but will remain effective over a period of years. Generally mastic cements cannot be relied upon to retain the necessary plasticity over long periods, and it is preferable to aim at joints which are intrinsically watertight.

INSULATION OF HOUSES FROM GROUND MOISTURE

47. The function of the damp-proof course in the walls of a house, and the need for adequate ventilation of the space between timber floors and the ground, are usually fully appreciated and need not be considered here. In the inter-war period there has been a development in the use, for ground floors of houses, of floors consisting of a layer of concrete laid direct on the ground with a wearing surface, commonly with a boarded finish or of linoleum or rubber. In this type of construction much trouble has been experienced due to failure to appreciate the need for proper insulation of the timber or linoleum from damp penetration from the ground. Reliance has wrongly been placed on the concrete to provide adequate protection.

48. It is often supposed that concrete is by itself impervious to moisture. While structural quality concrete can be almost impervious, much of the concrete used on the ground as a base for solid floors is of poor quality, and although, even with poor quality concrete, the surface may appear dry, this apparent dryness is due

to the fact that the moisture evaporates as fast as it comes through the concrete. If, however, the concrete is covered so as to retard evaporation, moisture will accumulate. The fixing of impervious coverings such as linoleum, rubber sheeting, wood-block floors or boarded floors direct on concrete will cause moisture to accumulate under these coverings and defects will inevitably arise. It is therefore essential that an adequate damp-proof course should be inserted in the floor. The position of the damp-proof course will be determined by the type of flooring, and must be considered in conjunction with the damp-proof course in the surrounding wall. The impervious layer in the floor and the damp-proof course in the walls should form a continuous membrane over the whole area of the ground floor, and, if these are not at the same level, a vertical damp-proof course should be inserted to connect them. With sheet materials such as linoleum or rubber flooring applied direct to the concrete a damp-proof course should be inserted in the thickness of the concrete, *e.g.* below the screed on which the floor covering is laid.

49. With wood-block or boarded floors it is sufficient to provide a thick coating of bitumen (or tar) over the surface of the concrete; fixing fillets in the latter case should be pressure impregnated with creosote to prevent dry rot. (See *Forest Products Research Bulletin No.* 1, *2nd edition.*)

DAMP PENETRATION THROUGH ROOFS

50. The flat roof covered with either built-up bitumen, felt or asphalt can give complete security against damp penetration. In the past trouble has been experienced on account of faulty design of detail, especially at the junction of the roof and walls. Parapet walls are a common source of trouble.

51. Pitched roofs if constructed in accordance with good practice are satisfactory. The incorrect use of traditional roof coverings, *e.g.* laid with too flat a pitch or insufficient lap, was common during the inter-war period and led to trouble.

CONDENSATION

52. Condensation is the result of the deposition of moisture from the air inside the building. The physical facts underlying the appearance of condensation are simple. Air always contains a certain amount of water vapour. The amount it can hold depends on its temperature; the higher the temperature the greater the amount. It usually does not reach complete saturation and the actual water content expressed as a percentage of that necessary for complete saturation at the same temperature is known as the relative humidity of the air. It follows then, that if air is cooled, a temperature will be reached at which the amount of water held as vapour is just sufficient for complete saturation and further cooling must result in deposition of moisture in liquid form. The temperature at which this occurs is known as the "dew point."

53. In a heated building, in winter, the temperature at the internal surface of any outside wall is, in general, intermediate between the inside and outside air temperatures. So long as air is merely being drawn into the building and warmed, without the opportunity of taking up more water, no condensation can occur. Usually, however, there are sources of moisture within the building and the warmed air is able to increase its moisture content, with a corresponding rise in its dew point. If any wall surface within the building is below this dew point, condensation will occur upon it. The risk of condensation under such circumstances will depend on the structure of the building—for a wall of high thermal transmittance will always present a colder face to the air within the building than

one which is well insulated—and also upon the amount of free water available. In unfavourable conditions the deposition of moisture may persist for long periods and for this reason is called "permanent" condensation.

54. In another set of conditions, namely, when a spell of cold weather is succeeded by warmer and damper weather, damp air from outside enters the building through the ordinary process of ventilation; the fabric of the building is still relatively cold, however, and consequently moisture again makes its appearance on the surface. As soon as the fabric gets warmed up to the new prevailing temperature, this condensation will disappear and for that reason it is conveniently described, in contradistinction to permanent condensation, as "temporary" condensation. It follows that the smaller the thermal capacity of the fabric the more readily it will be heated and the sooner will this temporary condensation cease.

55. It will be obvious that adequate heating of buildings is an important counter against condensation. Equally, good ventilation plays its part in the case of permanent but not in that of temporary condensation. The best and most permanent method of preventing condensation is to decrease the thermal transmittance of the fabric, which inhibits "permanent" condensation, and to provide an internal lining of low thermal capacity which will tend to reduce "temporary" condensation. Both these objectives can be attained at one and the same time, by the use of an internal lining which serves to lower the heat-conducting properties of the fabric and to provide a surface which will readily adjust itself to changes of temperature. Heating coupled with good ventilation in the case of permanent condensation will serve to remove the dampness due to condensation. Absorbent surfaces have their uses in preventing the appearance of moisture, although they do not, in fact, prevent the actual condensation.

THERMAL INSULATION

56. The weight of coal consumed annually for domestic purposes in Great Britain is about 55 million tons, and its cost equal to that of building 200,000–300,000 houses. A reduction in this consumption would be of importance both to the nation, in the conservation of fuel resources, and to the individual, in a smaller expenditure on heating.

57. In any building, the capital expenditure on additional thermal insulation should be justified by a consequent reduction in costs of heating. Inadequate thermal insulation in a building can be counteracted by an increase in heating alone. This would be a reasonable course if fuel was plentiful and relative prices were such that it was cheaper to increase the heating than to increase the thermal insulation; but this is not the case at present.

58. Since the problem is one of balancing capital costs against running costs, it is not possible to lay down absolute standards of thermal insulation as has been done in the case of Strength and Stability. Each problem must be analysed separately and the balance struck between capital and running costs in the light of the relevant facts. It is possible, however, to suggest the degree of thermal insulation which is likely to be found economical in any class of buildings by an examination of typical examples. The degree to which insulation will be practical may be profoundly affected by the reduction of price of insulation which may follow increased demand. The small house of normal construction (11-in. cavity walls of brick, timber floors and pitched roof) has been examined for this purpose, and as an example of the kind of calculation which is necessary for each element of the building, the ground floor is analysed below. The example is of a house with a ground floor area of 375 sq. ft. of which 184 sq. ft. is in the living room. The floor

construction is of 1-in. (nominal) tongued and grooved boarding on timber joists, with a well-ventilated air-space underneath. The covering is thin linoleum.

The annual heat loss (calculated) from the house, when adequately warmed, is of the order of	24 million B.Th.U. [1]
The cost of room heating has been assumed on the basis largely of a Survey by the Ministry of Information to be . .	£10 per annum.
Therefore the cost of 1 million B.Th.U. lost from the dwelling is	$\frac{£10}{24}$ = 8*s.* 4*d.*
The annual heat loss (calculated) through the whole of the ground floor area (375 sq. ft.) is	5·1 million B.Th.U.
Cost of heat loss through the ground floor (at 8*s.* 4*d.* per million B.Th.U.) = 5·1 × 8*s.* 4*d.*	= 42*s.* 6*d*
Cost of heat loss per sq ft. of ground floor $\frac{42s.\ 6d.}{375}$	= 1·3*d.* per sq. ft.

For the living room alone the heat loss per sq. ft. would be higher, as it is kept warmer than the rest of the house. The figures are:

The annual heat loss (calculated) through the floor (184 sq. ft.) is	3·1 million B.Th.U.
Heating cost (at 8*s.* 4*d.* per million B.Th.U.) = 3·1 × 8*s.* 4*d.*	= 26*s.*
Heating cost per sq. ft. of living room floor $\frac{26s.}{184}$	= 1·7*d.* per sq. ft.

59. With the interest rate at $3\frac{1}{2}$ per cent., a capital outlay of 1*s.* entails an annual charge of about $\frac{1}{2}d.$ to cover the interest and the repayment of capital (over 40 years). If the heat loss through the ground floor of the whole house could be halved, and consequently the cost of heating halved, for the expenditure of 1*s.* per sq. ft. on insulation the rentpayer would be no worse off (paying, in round figures, $\frac{1}{2}d.$ per sq. ft. on account of the capital outlay, $+\frac{1}{2}d.$ for heating, instead of 1*d.* for heating) and the conservation of national fuel resources would be aided. If the same saving could be achieved for the expenditure of less than 1*s.* the rentpayer also would benefit by a reduction in his total expenditure on rent plus heating. For example, if the heat loss could be halved for an additional expenditure of 6*d.*, he would pay $\frac{1}{4}d.$ on capital $+\frac{1}{2}d.$ for heating, instead of 1*d.* on heating.

60. By the same reasoning, a sum of about 1*s.* 6*d.* could be spent on halving the heat loss through the floor of the living room without increasing the expenditure of the occupier, who would benefit directly if the cost was less than 1*s.* 6*d.*

61. The heat insulating quality of any construction is inversely proportional to its heat transmittance coefficient, indicated by the symbol "U," which represents the number of B.Th.U.'s transmitted through one square foot of the construction in one hour when there is a difference of temperature of 1° F. between the indoor and outdoor air-temperatures. The lower the value of U, the higher is the insulation. The value for U for the suspended and ventilated floor construction in the example is 0·35. To reduce the heat loss of that floor by half it would be necessary to reduce the value of U to 0·17. A reduction could be achieved in various ways; one of the easier would be to use a solid floor rather than a suspended one, as the main source of heat loss in the latter is the necessary ventilation of the under-floor space.

[1] The amount of fuel needed to supply this heat depends on the efficiency of the appliance and the method of use.

Thus, for a solid concrete floor, laid direct on the ground or on hardcore, with a 1-in. wood-block finish, the value of U would be 0·15; and 57 per cent. of the heat loss through the suspended floor would be saved.

62. A similar analysis can be made for the other elements of the house, and in most cases it will be found that additional capital expenditure on insulation will be justified. For instance, double glazing or double windows would lead to substantial economies.

63. The amount of fuel saved by insulation will depend to some extent on the method of heating which is employed. If the appliances are fully controllable, so that the heat output can be closely related to the heat requirements, the theoretical saving should be achieved, which means that the full benefit of the thermal insulation will be obtained. This will not be obtained with present-day solid-fuel appliances, which have a minimum rate of burning, below which the fire goes out. This minimum rate of burning produces so much heat that in spring and autumn overheating may result, and in these circumstances the saving of fuel as a result of thermal insulation will not be great. In winter, when the minimum rate of burning does not give the heat required, the insulation of the house will have its full effect in reducing the fuel consumption. The importance of insulation will grow with the improvement of solid fuel appliances and it would be unfortunate if houses were not well enough insulated to gain the full advantage of that improvement.

64. It is suggested that the following maximum values for heat transmittance coefficients will prove economical:

a. In houses in which the apparatus allows of full control over the heat output

External walls of living room	U not to exceed 0·15
„ „ „ rest of the house	„ „ „ 0·20
Ground floor	„ „ „ 0·15 [1]
Roof and top floor ceiling (together)	„ „ „ 0·20

b. In houses in which the apparatus does *not* allow of full control over the heat output

External walls of living room	U not to exceed 0·20
Ground floor	„ „ „ 0·15 [1]
Roof and top floor ceiling (together)	„ „ „ 0·30

65. Still lower values (*i.e.* a higher standard of insulation) are to be preferred where they can be economically obtained; but it follows from what has already been said that the *full* benefit of the thermal insulation would not be obtained unless apparatus capable of full control was installed.

66. The following examples which fulfil the above requirements are given to indicate the kind of improved construction needed; the examples are not necessarily to be recommended from other points of view.

EXTERNAL WALLS

11-in. cavity brick wall, ½-in. fibreboard on battens	U = 0·18
6-in. foamed slag concrete, 1½-in. wood-wool (permanent shuttering)	U = 0·15
¼-in. asbestos cement, 2¾-in. wood-wool; cavity; ⅜-in. plasterboard	U = 0·14

[1] Normally the temperature difference across the floor (air inside to earth) will be less than that across the external wall (air inside to air outside). The true value of U for the solid ground floor is adjusted so that, in calculating the heat loss through the floor, these two temperature differences can be assumed to be the same.

GROUND FLOOR

Wood-block floor on concrete direct on ground .	U -0·15 [1]

ROOF AND TOP FLOOR CEILING

Tiles on battens, boarding and felt ; plaster ceiling .	U -0·30
Tiles on battens, and felt ; ½-in. fibreboard above ceiling joists ; ½-in. fibreboard ceiling . .	U -0·17
Asphalt on 6-in. concrete, 2-in. light-weight concrete screed ; ½-in. fibreboard on battens on soffit .	U -0·20

67. In many cases it will be possible to apply the insulation in the form of linings to the interior of the walls, and, as a general rule, for intermittent heating, it is preferable for the insulation (whether of floor, walls or roof) to be on the inside surface. When so applied, it is possible to warm a room more readily than if the inner surfaces have a high thermal capacity (such as surfaces of plaster, masonry or concrete). Not all insulating materials are equally good in this respect, and the descending order of merit is approximately fibreboard, plywood, and hardboard and plasterboard. A similar lining may be applied to the party and partition walls also. These linings need only be thin, for thickness has very little effect on the rate of warming of such materials. Since the use of these low thermal capacity linings reduces the time required to make the room comfortable for occupation, when heated intermittently, there is a saving of fuel over and above that due to the smaller heat loss, and as has already been noted, such linings reduce the risk of condensation. With continuous heating low thermal capacity linings on all walls would not be justified from the thermal point of view; insulation of the external walls would of course still be valuable.

68. Enough has been indicated in the foregoing notes to show that the problem of providing ground floor insulation for the dwelling—whether house or flat—is not a difficult one for the building industry to solve. The roof system is also a comparatively simple problem: the logical treatment for a pitched roof is to concentrate the insulation on the top of the ceiling joists—the amount of material required is nearly halved thereby. Tanks and pipes in the roof space should be cased: there is some advantage in leaving out the insulation of the ceiling below the casing for tank and pipes, as the heat flow from the house helps to prevent freezing. Felt immediately under the slates or tiles is very valuable, as not only does it prevent occasional rain or snow leakage, but it also stops air infiltration and the consequent heat loss. Similarly the junction of wall and eaves should be protected by beam filling between the rafters or other equivalent.

69. For flat roofs, insulation below the roof deck is preferable from the thermal point of view, but in this case expansion joints will be needed. Insulation on top of the concrete may give rise to trouble with asphalt coverings unless these are properly laid., A white treatment, such as the incorporation on the surface of white chippings would be a valuable addition. (See *Annual Report of Building Research Board* 1936*; Wartime Building Bulletin No.* 7.) A screed of light-weight concrete may be used instead of ballast concrete, and this will improve the insulation of the roof. It may be mentioned in passing that the standard of insulation suggested would reduce the heat gain in summer and add materially to the comfort of the occupants.

70. The walls of the normal brick-built house are a more difficult problem. The cavity brick wall provides protection against rain and is adequately strong, but as previously indicated is inadequate in thermal insulation particularly for a living room. In the example quoted above the additional insulation was obtained by substituting an insulating board lining for the normal plaster. As an alternative

[1] See footnote on opposite page.

it is possible to use a highly insulating building block for the inner leaf of the cavity wall.

71. Where alternative methods of construction are used there are many ways of securing high values of insulation. Especially is this the case when the loads are carried by a framework, as the panel fillings can be chosen with heat insulation as a primary requirement.

SOUND INSULATION

SOURCES AND TRANSMISSION OF SOUND

72. Sound in buildings usually originates in one of two ways:

a. As a disturbance in air, such as the human voice or music from an instrument, which is usually termed "air-borne" sound.

b. As a blow or impact applied directly to some part of the building structure, in which case it is called "impact" sound. Examples are footsteps, the moving of furniture and the noise of equipment fixed to some part of the carcass of the building.

73. Sound from a room becomes "noise" or unwanted sound in an adjacent room or building. The object of sound insulation is to reduce the transmission of sound from its source to other parts of the building or to other buildings.

AIR-BORNE SOUND

74. Air-borne sound is transmitted by free air paths, such as open windows, cracks in walls and around doors, or across and along continuous structures. When sound is transmitted across a wall or floor, from one side to the other, it is customary to speak of the transmission as being by the direct path. Sound which travels along the structure by a flanking wall or floor is said to be transmitted by an indirect path. The importance of the latter was often overlooked in the past, and treatment of the direct path only was sometimes recommended. It is now known that the indirect paths are often of equal importance in the transmission of sound in rigidly continuous structures such as those of brick or stone.

75. The insulation of air-borne sound between two rooms is measured as a reduction of energy in decibels (db.). One decibel represents about the least difference in intensity which a sensitive ear can detect; a change of about 5 db. is required in practice to give an appreciable improvement or reduction. The efficiency of insulation is usually measured at several frequencies, and the average of these measurements is called the average reduction factor for the construction.

IMPACT SOUND

76. Impact sounds arise from the vibration of the structure itself, and the sound of a footstep on a concrete floor will usually be as loud, therefore, in the room below as in the room in which it is made. In this sense the floor does not provide insulation: it is itself the source of the sound. Insulation is achieved by preventing the impact from vibrating the floor.

77. This gives rise to a difference in the technique of measuring impact insulation. The reduction of the noise cannot be stated as an overall reduction from one room to the next, but only as a reduction compared with the noise generated by hitting the bare, untreated floor. Thus the degree of insulation against impact noise by a construction is stated in terms of its improvement over the untreated structure. Insulation against impact noise is measured in a different unit, the phon, which is a measure of loudness (*i.e.* the loudness as detected by the ear), as compared with the decibel, which is a measure of energy in the sound, and does

not correspond directly with the sensation registered by the ear. These two units may be considered equivalent to a limited extent, for the distinction is more necessary for the purpose of scientific measurements than for the design of buildings. Care should be taken not to extend the idea of equivalence too far, but for present purposes it is fair to say, for the phon as for the decibel, that increases of about 5 units are required to give an appreciable improvement in practice.

STANDARDS OF SOUND INSULATION

78. Insulation against noise is of growing importance in the design of flats and houses. The modern trend towards less bulk and weight in building construction has lowered the resistance to noise, while noise has increased with the growth of traffic, radio and aircraft. Research now makes it possible to suggest the standards of sound insulation which should be provided in residential buildings and the means of achieving them.

AIR-BORNE NOISE

79. INSULATION BETWEEN DWELLINGS. Radio is a greater cause of annoyance than most other air-borne noises. Most of the power of the instrument is often used because, within limits, this leads to better quality reproduction. The average intensity of sound in a room with a radio playing may be of the order of 70 to 80 db., though it will obviously vary a good deal. The values of the insulation of prevailing types of construction are below this level, and figures for some typical constructions are as follows:

STRUCTURE	WEIGHT PER SQ. FT.	AVERAGE INSULATION DECIBELS (TO NEAREST 5 DB.)
HOMOGENEOUS CONSTRUCTIONS		
½-in. fibreboard	0·75 lb.	20
Window glass	1·5 ,,	25
¼-in. plate glass	3·5 ,,	30
2½-in. clinker block, plastered	20 ,,	35
4½-in. brick, plastered	55 ,,	45
9-in. ,, ,,	110 ,,	50
SEMI-DISCONTINUOUS STRUCTURES		
Boarding on joists, plasterboard ceiling	—	35
,, ,, ,, lath and plaster ceiling	—	45
,, ,, ,, lath and plaster ceiling plus pugging 20 lb. per sq. ft.	—	50
Timber stud partition, lath and hard plaster both sides	—	45
,, ,, ,, lath and plaster ceiling, plus floating floor of boarding on battens on quilt	—	55
FULLY DISCONTINUOUS CONSTRUCTION	—	65 and upwards

80. With solid partitions, weight is a factor in insulation; the heavier the better, and therefore lightweight or hollow blocks are disadvantageous. The 9-in. brick party wall is the subject of frequent complaints as a sound insulator against the noise of radio, which suggests that it has too low a value in this respect. An insulation of 60 db. (10 db. better than 9-in. brickwork) has been measured as the reduction value between specially treated semi-detached houses known to

give satisfactory results in practice, but this might reasonably be taken as representing "best practice." A standard half-way between this and the 9-in. wall, namely 55 db., is suggested as desirable.

81. Insulation of the suggested standard should be provided between certain rooms. The source of the loudest noises, such as those from the radio or the piano, is usually the living room or parlour, and in a neighbouring dwelling it is the same rooms, together with the bedrooms, in which quietness is required. A standard need be applied, therefore, only between these rooms in adjoining flats or houses, and not between such rooms as kitchens and bathrooms. This will leave open the possibility of securing the suggested standard of insulation by planning measures, such as separating the living rooms and bedrooms in one dwelling from those in another by kitchens, bathrooms, stair-halls, garages, and so on. This aspect is dealt with more fully below.

82. INSULATION WITHIN DWELLINGS. Within a single dwelling the needs of insulation are less urgent, but cannot be altogether disregarded. The needs of night-workers who must sleep by day, and of the children who have to do home-work or practise music, must be considered. To satisfy these needs it has been suggested that one room in the house should have a suitable standard of insulation, and, since the living room is the most likely source of noise, it is wise to provide that insulation there.

83. It seems excessive to suggest that the standard given by the 9-in. brick wall, namely 50 db., be applied to the living room insulation, but it can be said confidently that the 35 db. reduction given by a breeze block partition is not likely to be adequate. This leads to the suggestion that 45 db. might be taken as a desirable reduction factor between the living room and the other rooms of the house, with the exception of the service rooms. A reduction of 45 db. is achieved by such constructions as 4½-in. brickwork or concrete, lath and plaster on studs, or a timber joist floor with lath and plaster ceiling.

84. Between the other rooms of a house, especially the bedrooms, the requirements are not severe. A breeze block partition weighing about 20–25 lb. per sq. ft. gives adequate insulation; the reduction factor is about 35 db.

85. A surprising amount of sound can escape round the rebate of a door, even when it fits fairly well, and the light weight of some types of door also contributes to sound transmission. Methods are available by which the closure of a door can be made more effective, but they are not widely enough known. Perhaps the cheapest and easiest treatment for general use would be the development of a rebate carrying a continuous resilient bead. Doors should be selected which are robust, and preferably not of the single panel type.

IMPACT NOISE

86. All the above references are to air-borne sound. Of no less importance, especially in flats, are impact sounds. Complaints of such noises in flats have led to undesirable restrictions on the occupants, such as prohibition on the residence of children and the requirement of close carpeting.

87. The problem of impact noise was discussed in the *Final Report of the Departmental Committee of the Ministry of Health on the Construction of Flats for the Working Classes*, prepared in 1937. The Committee noted, in Appendix III of their report, that insulation gains of at least 10–15 phons over a bare concrete floor would be required as a minimum, and that 25–30 phons would be very acceptable. At the time, however, research had not produced any sufficiently inexpensive treatments to enable the Committee to make a firm recommendation. The position has since altered, and it is now safe to recommend as a standard a minimum of 15 phons improvement over a bare concrete floor (or 20 phons over the normal timber joists floor which is basically a little noisier than concrete); these standards

could be achieved with ease and at reasonable expense. Suitable methods will be mentioned later.

88. The standard would apply to the floors over bedrooms and living rooms, when the rooms overhead are part of a separate dwelling as in flatted houses. There is no evidence of serious complaint from floor noises within a dwelling

89. Figures for noise reduction against impact in various types of construction are given in the tables below:

REDUCTION OF IMPACT NOISE

Timber Floors

TREATMENT	NOISE REDUCTION PHONS
Normal board and joist floor, lath and plaster ceiling	
Carpet on underfelt	10
Plaster on plasterboard ceiling	0
Pugging, sand or ashes 10 lb. per sq. ft., or slag wool 2 lb per sq. ft.	
Sand or ashes 20 lb. per sq. ft.	
Floor boards on cross battens on glass silk quilt, not nailed	
Floor boards on cross battens on glass silk quilt, on sub-boarding	10
Separate joists to carry ceiling	5

Concrete Floors

TREATMENT	NOISE REDUCTION PHONS
Bare concrete	0
Carpets, etc.—	
Lino	5
Wood blocks, thin carpet, rubber	5–10
Carpet on underfelt	10
Sheet rubber on sponge rubber	20
Screeds, 2-in. thick, on following underlays—	
Clinker	5–10
Granulated cork, 1 in.	10–15
Slag wool quilt or eelgrass quilt	15–20
Glass silk quilt, single layer, or eelgrass quilt, double layer	20
Glass silk quilt, double layer	25
Boarding on battens on following underlays—	
Clips	5–10
Asbestos pads or felt pads, ½-in. thick	5–10
Fibreboard pads, ½-in. thick	10
Felt pads 1-in. thick or rubber pads ½-in. thick	10–15
Eelgrass quilt or slag wool quilt, ½-in. thick	10–20
Glass silk quilt, rubber pads 1-in. thick	15–20
Suspended ceilings—	
¼-in. plaster on ½-in. fibreboard on 2-in.×2-in. battens in clips	5–10
⅜-in. plaster on ⅜-in. plasterboard, on battens in felt-lined clips	10–15
No figures are available for metal lath ceilings suspended on metal supports, but their performance appears to be of the same order as above.	

NOISE FROM MECHANICAL EQUIPMENT

90. The position with regard to the noise from mechanical equipment is not so clear. The problems are associated largely with plumbing and in the case of flats with lifts.

91. In plumbing the need is particularly for quiet appliances, such as taps, ball valves, flushing mechanisms, and so on, though a great deal of the nuisance caused by equipment noise reaching one flat from another can be avoided by attention to planning and by insulating pipes and fittings from the structure; this applies particularly to the W.C. The pan should rest on rubber or be sunk in lino and the cistern should be carried on insulating brackets. Pipes should be wrapped where they go through walls to prevent solid contact. Research and development are at present proceeding with the aim of producing quieter equipment, but it will always be possible for architects to improve the sound conditions by careful selection of equipment and proper fixing, to which reference is made in two recent publications.[1]

SUMMARY OF SUGGESTED STANDARDS

92. Before dealing with methods for overcoming noise, the suggested standards are summarised below:

AIR-BORNE SOUND

	REDUCTION DB.
a. Between the living room in one dwelling and the living and bedrooms in another . . .	55
b. Between the living room and other rooms (except service rooms) in a dwelling . . .	45
c. Between other rooms (except service rooms) .	35

IMPACT SOUND

Between any room in one dwelling and the living or bedrooms of the dwelling below, 15 phons reduction as compared with a bare concrete floor, or 20 phons reduction as compared with a bare timber floor.

PRACTICAL MEASURES

93. The following information may be useful to designers as an indication of the method of approach to sound insulation problems, stated in terms of familiar materials and methods of construction. The best results in noise prevention will only be attained by careful consideration of siting, planning, and construction. Each of these plays an important part and the references already given should be consulted for further and more detailed information.

94. SITING. No reference has been made above to the standards of insulation from street noises. There is no doubt that in urban districts this is important, especially where houses or blocks of flats are erected near arterial roads on which traffic is heavy both by day and by night. When windows are open, little insulation can be assumed and most of the necessary noise reduction must be obtained by planning and siting. From data at present available, a set-back of at least 75–100 ft. from the road is necessary to effect a reasonable reduction of loudness; though baffles, either of trees or other buildings, will provide additional sound reduction.

[1] *Practical Acoustics and Planning against Noise*, by H. Bagenal (Methuen); *Sound Transmission in Buildings*, by R. Fitzmaurice and W. Allen (H.M. Stationery Office).

95. The solution of the problems of siting for noise reduction can be summed up as the avoidance of traffic noise by building away from main roads; by setting back from roads; by building at right angles to roads; and/or by baffles of trees or smaller buildings.

96. PLANNING. Considering first the problem of air-borne sound transmission between dwellings, it will be noted that the insulation standard suggested relates to specific rooms in the different dwellings, the living rooms and bedrooms, and does not relate to the dwellings as such. This leaves open the way for insulation by planning measures in some circumstances. For instance, if the living rooms in the adjoining houses can be separated by such rooms as the kitchens and stair-halls, then these, in addition to the normal party wall between the houses, would give the necessary insulation. In flats, and maisonettes, where the adjoining dwellings are above and below, as well as to either side, the introduction of service rooms to serve as "buffers" for insulation is not possible, at least in the vertical relationship, and in any case would add another source of impact noise. In blocks of flats planning has, however, another function, which is to separate the living rooms and bedrooms from the public access areas containing noisy stairs and lifts. An important aspect of flat design is to group the areas requiring quiet away from those where unavoidable noise occurs. If the living rooms in adjoining flats can also be well separated horizontally, from one another and from bedrooms in adjoining flats, this will be desirable.

97. CONSTRUCTION. Planning measures can seldom give the whole of the required insulation, and recourse is necessary to structural measures. In housing, these might take one of two or three general forms. Treatment of the party wall is one possibility, and a method has been tried in practice with success.[1] In this case the external walls were of cavity construction and the cavity was returned along the whole length of the party wall, dividing the adjacent houses and their chimneys by a 2-in. gap. No wall ties were employed, and the insulation proved to be of the order of 60 db., an insulation which, with solid construction, could in theory only have been attained by some 3 ft. of brickwork. The treatment was found to be inexpensive and is suitable for general use. On the building estate where the experiment was made it became the normal party wall construction. It does, however, actually exceed the suggested standard, and some simpler measures may be acceptable. For instance some twisted wire wall ties can probably be allowed in the cavity; and it may even be possible to allow the separate leaves to butt on to a solid chimney, where this is massive enough to effect the necessary attenuation of sound. This method, however, requires confirmation.

98. Another effective method of sound insulation is to line each living room with an inner shell of some kind. The nature of this shell would depend on the type of carcass of the building. Where brickwork or concrete is used, the carcass has a high degree of continuity, and sound is transmitted effectively by direct and indirect paths. To provide sound insulation it is necessary to prevent the sound from reaching the carcass, and the lining of the room has therefore to be complete as to walls, ceiling and floor (if the latter is not solid on the ground). It need not be an elaborate lining, however; quite a simple treatment for the walls and ceiling, such as lath and plaster battened out from the carcass, will do well, and for the floor one of the floating type which will be described later as a treatment for impact sounds will be adequate. It would be preferable to fix the battens in resilient clips, but this may not be essential. The ceiling probably would not need treatment if it were of joisted construction.

99. Quite different transmission problems are presented by other types of carcass construction, such as walls which consist of small frame members with linings

[1] See footnote on p. 24.

either side, rather like the traditional stud partition, and floors which are framed in the manner of the usual timber joist floor but with other materials. These constructions do not generally transmit sound along the member as effectively as do the constructions with a high degree of continuity, and therefore the risk of transmission by indirect paths is reduced. The inner skin of a wall or partition of this kind, or the ceiling of a framed floor construction, could thus form part of a lining or inner shell as described earlier, and nothing more probably would be needed to reduce transmission by indirect paths. The construction is obviously effective in this respect, but is less effective against direct transmission. These light constructions are more effective as insulators than might be expected, but it is difficult to improve them beyond, say, 50 db. without special treatment. Unless they can be improved, therefore, they are unsuitable as party walls or party floors for the separation of the living and bedrooms of adjoining dwellings. In some of the types of construction suggested for post-war use it is apparent, in fact, that although generally of frame construction, they would require more robust party walls than are proposed.

100. The sound insulation of frame constructions requires further study before their behaviour in this respect can be forecast accurately; much depends on the character of the lining and the stiffness of the frame. From the point of view of sound insulation, the best linings, so far as is known, are the simple types of plaster on lath; various sheet materials have been found much less satisfactory.

101. The normal timber floor which is often used as a party floor in two-storey blocks of flats is altogether inadequate for air-borne or impact sound insulation, and requires considerable treatment to bring it up to the standard. Experiments have shown that the standard could only be attained by some such combination as lath and plaster ceiling, heavy pugging between the joists, and a floating floor,—complications which suggest that party floors of concrete are desirable.

102. Impact sound on floor can, so far as is known, only be effectively treated by what is known as the floating floor. The standards suggested for impact sound cannot be obtained by any of the normal wearing surfaces, such as carpets, rubber, or lino, which give, at most, about 10 phons improvement. It has been found that a floating floor such as a timber raft, of boarding on battens, or a concrete screed, laid on resilient quilts (such as those of eelgrass and glass silk), will provide sturdy constructions giving the necessary insulation. Treatments as simple as these need cost very little, and one case is known of the boarding-on-batten treatment being laid in a block of working-class flats at a cost little, if at all, in excess of the normal construction, as the cost of the quilt was balanced by the cost of the clips which would otherwise have been used. The floating screeds will cost a little more, the extra cost being that of the quilt, as the screed is normally laid direct to the sub-floor. The quilts cost before the war from, say, 1*s.* 6*d.* a yard to 2*s.* 6*d.* a yard laid. There would appear to be a future for the manufacture of large factory-made sections of floor finish, having insulating qualities and with facilities for quick and easy fixing to the sub-floor.

103. These floating floors can be combined with the other linings in a room to form the inner shell which has been described as one alternative treatment for air-borne sound insulation.

104. Where a rigid frame is continuous from house to house, there will be a ready path for sound transmissions, especially for impact noises. Unless special steps are taken to overcome this as, for example, by the use of floating floors, then it will be necessary to break the continuity of the frame at the party wall.

105. In the references already given, more complete descriptions will be found for the treatment of doors, windows, fireplaces, floors, and other points where risks of a short-circuiting of the insulation will occur.

FIRE HAZARD

A. ONE- OR TWO-STOREY HOUSES IN SINGLE OCCUPATION

106. The precautions taken against fire hazard in houses with brick and stone walls, timber floors and with roof timbers covered externally with slates or tiles (later referred to as "normal construction") have been developed over many years, in the light of experience. Some safety measures which go back to an early date have been modified (*e.g.* the party wall need not now be carried through the roof in all cases) while others have been added from time to time (*e.g.* as recently as 1938 a measure dealing with the construction of hearths was introduced into the Model By-laws). As a result, the house of normal construction is regarded as affording satisfactory structural protection against fire.

107. It does not follow, however, that the standard of fire protection provided by the normal brick construction should be adopted as the standard by which to judge the protection from fire given by alternative constructions. For example, in some respects, the use of brick automatically ensures a standard of fire protection above that which is required. Therefore, it is desirable to review the real needs from first principles by considering the nature of the hazards against which protection must be provided. The assessment of the fire risk in any system of house construction involves the consideration of three factors; firstly, the risk to the personal safety of the occupants, which is called the *personal hazard*; secondly, the likelihood of the house catching fire from a neighbouring fire, or the likelihood of a fire in the house endangering neighbouring houses, or of the house being endangered by any adjoining fire risk (*e.g.* a stack of timber) which is called the *exposure hazard*; and thirdly, the possible effect of a fire on the house itself, especially on the party wall, which is called the *structural hazard*, and which must be considered in its relationship to exposure hazard, which would be increased by the collapse of the external walls. While many data are available on the resistance of structural elements to the effects of fire, the factors which need consideration in assessing personal hazard and exposure hazard have not received the same attention. A certain amount of work has been done during the war, but it is not yet possible to lay down hard and fast requirements, and the assessment must be based largely on experience.

PERSONAL HAZARD

108. The most serious threat to the personal safety of the occupants in case of fire occurs if their escape from the house is prejudiced. To facilitate escape, three conditions should be observed.

i. The structure should not ignite easily (from, for example, sparks, or a dropped match). Furniture and furnishings are often the most easily ignited materials in the house, and the risk from this source is the same for all forms of house construction.

ii. The structure must be such that a fire, once started, does not spread rapidly from one room to another or in staircase and passage.

iii. There must be adequate means of escape, especially from the upper floor.

109. The first two conditions are important mainly in the early stages of a fire, and are largely determined by combustible linings, partitions, floors, ceilings, doors, and staircases: the third condition is common to all types of house construction. The danger of a combustible lining can best be appreciated by reference to examples. It is clear that the ease of ignition of certain types of laminated wall linings would increase the chance of an outbreak of fire and the rate of spread of fire over such a lining could make the escape of the occupants very difficult. On the other hand, a structure built wholly of concrete and brick would present no such risks. Between

these cases there will be a gradation of risk, depending on the material. In normal construction the wall surfacing is incombustible (paper would not spread flame when fixed to walls) and fire would first develop in the furnishings. Escape from a room in which a fire has started will obviously be hindered where the wall surface is combustible, *e.g.* untreated fibreboard on battens. Such materials are easily ignited, and spread of fire is rapid; instances are known where, within a minute or two of the outbreak, escape was jeopardised. This does not imply that combustible boards, protected by treatment or associated with incombustible materials, need necessarily be excluded from all forms of construction of small dwellings, but is intended to convey that further close consideration would be necessary as to the manner in which such boards are proposed to be protected or incorporated in the construction before any general approval could be recommended.

EXPOSURE HAZARD

110. The exposure hazard may be defined as the risk of a building catching alight from a fire external to it but not necessarily in direct contact with it. In normal construction the only appreciable risk arises from window frames and other exposed timbers.

111. In the case of larger buildings, special precautions are often necessary to reduce the risk of spread of fire from building to building. For houses the necessary safety can best be obtained by suitably spacing the houses and limiting the size of blocks. Broadly speaking, a light wall construction would, for example, tend to create a greater risk to near-by houses than one of, say, brickwork, and it is on these principles that existing requirements are based. These requirements are by no means stringent when considered in the light of modern development, though special precautions are imposed in the case of houses with combustible external walls and roofs. For details of these requirements, which are summarised below, reference should be made to building by-laws made by local authorities (which are almost invariably based on the Model By-laws of the Ministry of Health, Series IV, clauses 25 to 53 (as to walls) and 78 (as to roofs)). These requirements may be reconsidered in the light of further experience.

Domestic Buildings with External Walls and Roofs having Combustible External Coverings

Summary of requirements for protection against Exposure Hazard. (See Ministry of Health Model By-laws, Series IV–1937, for full details. As regards Scotland, the relative provisions are contained in the Model By-laws made under Section 70 of the Housing (Scotland) Act, 1935.)

(*N.B.* "Domestic buildings" includes such buildings as shops and offices as well as houses.)

METHOD OF CONSTRUCTION	RESTRICTION ON SIZE, ETC.	REQUIREMENTS AS TO SPACING
Roof covering of combustible material (*e.g.* thatch).	—	Building to be twice its height from the nearest boundary and from any other building.
Walls with a combustible frame covered with combustible material.	Single buildings or pair of buildings only (with incombustible party wall). Not exceeding two storeys high. No single building to exceed 36,000 cubic ft. capacity; no building in a pair to exceed 18,000 cubic ft. capacity.	Building to be 10 ft. from boundary (other than street) if its capacity does not exceed 18,000 cubic ft. or 20 ft. if the capacity is greater.

METHOD OF CONSTRUCTION	RESTRICTION ON SIZE, ETC.	REQUIREMENTS AS TO SPACING
Walls with a combustible frame filled or covered with incombustible material.	A. Building limited to two storeys high. Not more than four buildings in a block (with incombustible party walls). No single building to exceed 36,000 cubic ft. capacity; no building in a block to exceed 18,000 cubic ft. capacity.	Building to be 5 ft. from boundary (other than street) if its capacity does not exceed 18,000 cubic ft. or 10 ft. if the capacity is greater.
	B. Building limited to three storeys high. No more than four buildings in a block (with incombustible party walls).	Building to be 8 ft. from boundary (other than street) if one or two storeys high, or 16 ft. if three storeys high. (Half these distances where this method of construction is confined to a bay or a gable.)

STRUCTURAL HAZARD

112. PARTY WALLS. In dealing with problems of structural hazards in buildings generally, it has become an accepted principle that efforts should be made to contain a fire within certain defined sections of the building by the provision of suitable walls and floors; these sections do not necessarily coincide with the individual rooms of the building. The main structural elements are designed to withstand, for a specified time, the severity of any fire that may take place, having regard to the combustible content. Because of the small area of the average house no sub-division within each house is called for, and the principle need only be applied to the extent of providing a continuous party wall which will form an unbroken barrier to the spread of fire from one house to the next. The standard of protection which it is reasonable to require of a party wall must necessarily take account of the combustible content (furniture and other combustible material in the structure, etc.) of an ordinary dwelling, and, by comparison with many other types of building, this is low.

113. It has been the general practice to require party walls to be not less than 9 in. thick of bricks, solid blocks or concrete. Tests have shown that this provides the highest degree of fire resistance defined in the *British Standard Definitions* (*No.* 476, 1932) for Fire Resistance, etc., namely six hours; it would restrict the spread of a fire in a heavily stocked warehouse. In practice this fire resistance is considerably less where such a wall supports built-in timber joists. Examination of burnt-out buildings containing about the same amount of combustible material as the average house has shown that a wall having a degree of fire resistance, as measured by the standard test, of less than two hours has successfully withstood the spread of fire; even a wall of one hour fire resistance would be sufficient in some respects. Because the test cannot take account of factors which may reduce the standard of protection in practice (*e.g.* development of cracks due to shrinkage or settlement, impact of heavy furniture, general instability) it is considered that a fire resistance of two hours, as defined in British Standard Definitions, would be adequate; with the additional proviso that the wall should be of incombustible material. It must be emphasised that in assessing the suitability of any system from the fire protection standpoint such factors as the above must be considered apart from the actual grade of fire resistance which the wall would attain in the test.

114. In general, a fire resistance of two hours is afforded by a solid wall construction having a thickness of about 4–6 in. In some systems of construction the party wall has been designed with relatively thin sheet materials with a cavity between the leaves. It might be possible to design such a wall which had the requisite grade of fire resistance but was inadequate in respect of other factors. It is considered that unless the linings themselves total 4–6 in. in thickness the cavity should be filled with concrete so that at least the same total thickness is obtained.

115. The inclusion of structural steel in party walls raises further problems. If the columns are built into a wall of cavity construction and carry steel-floor members, then collapse of the latter may damage the party wall; the risk may be dealt with in two ways:

a. By supporting the upper floor and roof on members not carried on the party wall. In this case, the framing must be designed to ensure that no breach will be caused in the party wall by the distortion of the members in the event of fire.

b. By protecting any steel-work in external wall, floor and roof construction which is connected with steel in the party wall so as to attain about half an hour fire resistance. Adequate protection would often be provided by ceilings and wall linings of incombustible material.

116. If the party wall is a load-bearing wall carrying the floors, the structural requirements will usually eliminate the risk of damage by fire arising from the possible collapse of unprotected steel-floor members.

117. Existing standards for chimneys, hearths, etc., should be followed where applicable; alternative schemes should afford equal safety.

118. The most common type of timber floor, *i.e.* square-edged boards on timber joists and ceiling of wood laths and plaster, which is accepted as satisfactory, has a fire resistance, as determined by the conditions laid down in *British Standard Definitions* (*No.* 476), of less than half an hour, *i.e.* it does not attain the lowest grade of fire resistance specified in the Definitions. With tongued and grooved boards or with less common types of ceiling, *e.g.* plaster on expanded metal, a ½ hour resistance is attained.

B. TWO-STOREY HOUSES FOR TWO FAMILIES

119. Buildings of two or more storeys used as flatted dwellings require further consideration. So far as two-storey buildings are concerned, the following additional requirements are proposed:

a. That the floor of the upper storey should have a fire resistance of at least half an hour. The supporting structure must be equally resistant to fire.

b. Steelwork should be protected to give a fire resistance of half an hour.

120. Exit requirements for two-storey flatted dwellings are under consideration.

GENERAL

121. It is inevitable that many points will arise in connexion with the fire hazard of new forms of construction. Two in particular should be mentioned:

a. The cavity between the inner and outer sheeting in frame construction provides a ready means of spread of fire and therefore the cavity should be properly fire-stopped (*i.e.* sealed with incombustible material to restrict spread of fire by way of the cavity) at first floor, eaves level, and wall junctions. This need not apply, of course, to brick or concrete walls.

b. In all cases the party wall should be carried through to the outer surface of the external wall, the joint being suitably dealt with by cover strips or other means. Care in the design of details will be needed to avoid accentuating sound transmission.

MAINTENANCE AND DURABILITY

122. Durability is a quality which cannot be assessed as precisely as those criteria discussed already. Past experience enables the probable life of houses built in traditional materials and methods to be estimated. Laboratory investigation and short-period tests make it possible to distinguish new materials and methods which will certainly be short-lived from those which are likely to last reasonably well, but any estimate of the length of life of the latter must be problematical. Much may depend on the care and maintenance bestowed upon them. For this reason, the durability of a building (defined as the length of time over which it will remain, or can be made to remain, efficient) can be assessed by an estimate of the probable maintenance which will be necessary. Experience of maintenance and costs on housing work is necessarily derived largely from traditional building.

123. The subject of maintenance, furthermore, must have relation to cost. In connection with working-class houses built under the Housing Acts by local authorities (a) under contract, or (b) by direct labour, the period for loan sanctions is 60 years for normal and traditional construction and 40 years for constructions which are deemed to be "permanent" but with a comparatively shorter life. For constructions which are obviously less durable or for additions to existing buildings the loan period is shorter.

124. Such loan sanctions whilst reflecting, empirically, the various standards of durability should in no way be looked upon as defining durability. It may with confidence be taken for granted that the well-built constructions of traditional form of the inter-war period will last with proper maintenance long after the loans are repaid and so become assets of some importance in the local authorities' finances.

125. The usual allowance for maintenance and redecoration on pre-war values has been about £5, 10*s*. per house per annum on dwellings for which a 60-year loan has been sanctioned, and from the detailed reports on special methods of construction in the inter-war period it will be noted that this has not varied materially for 40-year loan-period work. Whilst it is clear that £1 per annum saved on maintenance cost is the equivalent of about £25 capital expenditure, it must equally be borne in mind that to spend more than this to save the same maintenance expenditure is bad finance. As in all things the right balance between capital and maintenance costs and their effect on rents must be sought.

126. The durability of a building is partly dependent upon the practice of sound building construction. There are well-established principles, sanctioned by long usage, which are given in standard text-books on the subject. There is no point in attempting to set them out in this report. This section indicates some considerations affecting durability, which, though well established, are possibly not widely appreciated, and some other matters which will be of use in attempting to assess the durability of a construction. These will be discussed under the following headings:

A. Foundations and Rafts
B. External Walls
C. Renderings
D. Structural Roofs
E. Pitched Timber Roofs
F. Chimneys
G. Floors
H. (a) External Woodwork; (b) External Metal work
I. Roof coverings
J. Gutters, Flashings, Fillets, etc.
K. Internal Construction.

A. FOUNDATIONS AND RAFTS

127. Portland cement concrete is almost always used for the foundations of modern houses: its properties are well known and it is rarely a source of trouble. The use of aggregates of an unsound nature, *e.g.* certain types of clinker, or of aggregates contaminated with sulphates, *e.g.* brick rubble with adherent calcium sulphate plaster, may cause serious expansion, cracking and ultimately disintegration of the concrete. Gypsum present in the sub-soil may attack concrete foundations and cause disintegration. The rapidity and seriousness of the attack are influenced by the permeability of the concrete and the amount of sub-soil water present. For instance, dense concrete in reasonably dry soils would be only superficially affected, and, in fact, it is very rare to find any serious trouble in the relatively shallow foundations of houses. The expansion of site concrete containing unsound or contaminated aggregate may cause serious cracks in the external walls by pushing them outwards.

128. A reinforced concrete raft foundation is often used for houses if soil conditions are bad (*e.g.* made-up ground), and it cannot be emphasised too strongly that such a foundation, even for the light loading of a dwelling, must be subject to proper engineering design, with reinforcement correct in quantity and position in the slab. In similar conditions in Scotland, strip foundations are used but the brickwork up to damp-proof course level is reinforced; this has been found satisfactory. Where reinforced rafts are used, corrosion of the reinforcement may result from the presence of chlorides (usually sea salts) in the aggregate or from the use of permeable concrete. In either case spalling of the concrete may result from the expansion of the corroded metal and the strength of the foundation raft is thereby impaired.

B. EXTERNAL WALLS

129. Unsatisfactory design in detail or the use of unsuitable materials can give rise to a number of troubles in brickwork. Water penetration to the inner face of the wall may result from (a) using a jointing mortar which is too dense or too porous for the type of walling unit employed; (b) the omission or improper placing of damp-proof courses and cavity gutters; (c) inadequate eaves projection; or (d) faulty construction around openings, etc.

130. Where brickwork remains continuously wet, *e.g.* parapet walls without damp-proof courses, chemical reaction may occur between sulphates, in certain types of brick, and constituents of the cement of the mortar, and so cause the expansion and disintegration of the latter, with consequent distortion and cracking of the walls: unsound lime in mortar may produce similar results. Frost action on brickwork which is continually damp may lead to premature deterioration.

131. The commonest defect of concrete walls is the cracking due to drying shrinkage. In monolithic walls of dense concrete which are not reinforced to restrain such movement large irregular cracks may form and permit moisture penetration. The more successful work in unreinforced monolithic concrete walling has been in relatively lean mixes. In walls composed of small concrete units, *e.g.* blocks or bricks, or sand-lime bricks bedded in relatively weak mortar, fine cracks may develop between the units and the jointing mortar. Where a mortar stronger than the blocks is used the cracks which occur may be similar to those which are found in monolithic walls, and cracks may develop in the blocks as well as at the joints. Much can be done to avoid these types of cracking by proper control of the manufacture and curing of the units and by the use of a suitable jointing mortar. The relevant British Standards for concrete walling units specify the permissible drying shrinkage and moisture movement. Some types of concrete are not of themselves weather-resisting and must be rendered or otherwise treated externally.

132. The use, in external walls, of clinker aggregates containing unsound material has been a source of serious trouble by causing general expansion of the walls. Clinker aggregates should be used only when regular periodic tests in accordance with *British Standard* 834–1939 can be made to ensure soundness. In general, the moisture movement of clinker concrete has been too great for satisfactory use in external walling.

133. Where framed construction is used the external cladding frequently consists of prefabricated sheets of metal, cement concrete, asbestos cement, or other materials, sometimes of a laminated or composite structure. Walls of such sheet materials are most vulnerable to moisture penetration at the joints between the sheets and special care must be taken to obtain watertight joints. Probably the most effective method of jointing is by lapping as used in tiling, slating and with asbestos cement sheets. Such methods as caulking with mastic may ultimately fail; the mastic may harden and consequently crack, or become soft and run in warm weather, so that periodic replacement may become a serious item of maintenance. Cover strips have been successfully used for jointing claddings.

134. Sheet units vary in their properties and require different treatments. Steel sheets, for instance, must be adequately painted or otherwise protected against corrosion; other materials must be allowed some movement to avoid shrinkage cracking and open textured materials or those adversely affected by moisture, such as wood-wool, must be rendered or otherwise protected to prevent moisture penetration, excessive moisture movement, or decay. It is essential that the exposed edges of sheet materials which are corrodible or otherwise vulnerable to moisture or polluted atmosphere should be protected.

135. Framing may be of reinforced concrete, steel or wood. The proper protection of steel by encasement in concrete, by painting, or by other means, is of primary importance.

C. RENDERINGS

136. Most defects in renderings are due to (a) the properties of the base to which the renderings are applied, (b) inadequate preparation of the base, or (c) the use of unsuitable mixes. All mortars containing cement or lime shrink on drying and, if the restraint afforded by the base is insufficient, cracks develop. Rich mixes shrink more than those of weaker composition and greater stresses are set up. Strong mixes require a strong and rigid base with adequate adhesion at the inter-face. Weak materials such as clinker and soft brick are unsuitable as backings to such renderings. Their use may result in the tearing away of the surface of the base and the formation of wide cracks in the rendering. Generally, the tendency is away from strong, dense, highly trowelled mixes for use in external renderings. Metal lathing may, especially when fixed, lapped or tied in an unsatisfactory manner, become distorted by the drying shrinkage of an applied rendering, and the result is cracking of the rendering, moisture penetration and the corrosion of the lathing and fixings, causing ultimately a complete failure of the cladding. Metal lathing which is inadequately protected at the back by an applied rendering is also liable to corrode. Many common types of bricks contain sulphates and, under wet conditions, sulphate attack may occur on the jointing mortar and rendering as described in External Walls.

D. STRUCTURAL ROOFS

137. The exposure conditions on a roof are severe and there is always a possibility of local penetration of moisture at some time in the life of a house, so that there should be no doubt as to the quality of concrete aggregates used for roof work.

When unsuitable aggregate is used, concrete roofs are prone to the same troubles as concrete walls.

138. The thermal movements of roof slabs may result in the development of defects between parapet walls and their skirtings and of cracks in the external walls which permit penetration of moisture to the concrete slab, the masonry of the external walls and the interior of the house. The small detached or semi-detached house is hardly large enough for such troubles to be serious, but care is needed in the design of terraces and larger blocks of dwellings.

E. PITCHED TIMBER ROOFS

139. Pitched timber roofs give very little trouble: conditions in the roof space are generally not conducive to the development of "dry rot" and the traditional methods of construction are so well known that the framing is usually sufficiently well designed for its purpose. Flat timber roofs are more prone to fungal attack if the roof space is unventilated, particularly if parapets are used and the damp-proof courses are omitted or misplaced.

F. CHIMNEYS

140. The relatively severe exposure to which chimneys are subjected makes it essential that the greatest consideration should be given to their construction. To ensure freedom from trouble, the overhang of the chimney head should provide protection to the top of the masonry of the stack. Damp-proof courses should be provided under the head and immediately at the junction of the stack and roof covering.

141. Trouble has been experienced with chimneys serving domestic boilers or other types of slow-combustion stoves owing to the deposit of an acid condensate on the surface of the flue and the resultant sulphate attack. The trend of domestic solid fuel burning is in the direction of the wider use of slow-combustion appliances, so that the construction of flues and chimneys will need consideration anew. The problem is likely to be examined in conjunction with the design of the appliances. The provision of air inlets to flues and impervious flue linings are methods which have been used successfully.

G. FLOORS

142. The loosening and cracking of cement pavings are common occurrences. They are rarely caused by chemical reaction, being generally due to the normal drying shrinkage of the rich concrete paving combined with inadequate adhesion to the base concrete. Poor adhesion is in most cases caused by a failure to clean the surface of the base concrete adequately and to provide a satisfactory surface to which the paving will bond. Poor wearing qualities and dustiness are common and are due to the failure of the floor layers to observe the recognised rules of good concreting. Excessively wet mixes giving a surface layer of laitance are the most frequent cause of trouble.

143. Timber floors may be attacked by wood-destroying fungi, the most disastrous of these being the "dry rot" fungus (*merulius lachrymans*). Other types of fungi, though common, are usually less destructive. Before timber can sustain the growth of any of these fungi its moisture content must be 20 per cent., a condition which can only be reached where, by reason of faulty construction, water from the soil or from the outside can reach the wood and where inadequate ventilation is provided. Wider attention might be given to the recommendations given in

Forest Products Research Bulletin No. 1 (*2nd edition*) which deals with the common defects and safeguards against them.

144. Many modern floor finishes for concrete surfaces are unsatisfactory under damp conditions, *e.g.* magnesium oxychloride, linoleum, etc. Where these are used it is essential that the floor should have a continuous damp-proof course. Where certain types of product containing wood are used for insulation purposes under a ground floor finish, the same precaution is necessary to prevent fungal attack. Other types such as rubber latex with a wood filler are themselves useful as damp protection.

H (a). EXTERNAL WOODWORK

145. The proper protection of woodwork used externally is essential for durability. It is especially necessary to ensure that vulnerable parts of doors, windows and frames, *e.g.* bases of door frames and morticed joints, are kept watertight.

H (b). EXTERNAL METALWORK

146. All ferrous metals, especially those used externally, *e.g.* rainwater goods, steel windows, etc. require thorough painting or other protection. Near the coast and in industrial areas the corrosion of unprotected metal may be rapid.

I. ROOF COVERINGS

147. Roof tiles, if of poor quality, may laminate and disintegrate as a result of alternate wetting and freezing, and in some types florescence of magnesium sulphate may cause failure of the tile nibs.

148. The poorer types of roofing slates are affected by polluted atmospheres and may in certain areas disintegrate rapidly as a result of attack by acids. Low quality asbestos cement roofing materials may be similarly affected.

149. Zinc and steel roofs if unprotected are susceptible to acids in polluted atmospheres.

150. The corrosion of nails used for roofing purposes may cause considerable trouble. Galvanised, composition (yellow metal), copper and zinc nails have all a considerably longer life than unprotected steel nails.

151. Asphalt and built-up bitumen roofs have a reasonably long life if the materials are of good quality and the technique of laying is sound. Trouble has been experienced due to the disintegration of bitumen felts when laid under pervious pavings, *e.g.* tar macadam, tiles with vulnerable joints, etc.

J. FLASHINGS, FILLETS, ETC.

152. The use of cement fillets as a substitute for metal flashings has been a source of much trouble. The extra efficiency obtained by the use of metal outweighs the saving on first cost effected by the use of less durable materials.

K. INTERNAL CONSTRUCTION

153. There are few risks of serious deterioration of the materials used internally in houses unless continuous water penetration occurs, but in such circumstances

disintegration of plaster, moisture movements of timber, fungal attack, etc. may occur, and deterioration may be rapid.

154. In normal circumstances the main troubles experienced are the bursting of pipes and collapse of copper cylinders due to frost, corrosion of steel windows due to condensation, the decay of wood windows and the gradual wearing out of window and door fittings or the breakage of sanitary fittings, parts of grates and ranges, etc. It is important that pipe runs should be properly planned and pipes and cisterns protected where necessary to prevent freezing. The internal paintwork of windows should be kept in good repair.

GENERAL

155. It will be appreciated that most of the deterioration which occurs in houses is associated with water penetration and can be obviated by careful design and construction. Compliance with the existing codes of practice and British Standards will ensure the proper use of many materials and that these are of satisfactory quality. Where new materials are to be used consideration should be given to their properties as far as these are known, and, if necessary, tests should be made to provide some indication of their probable behaviour when used in building construction.

156. The durability of certain classes of materials depends largely upon the degree of protection afforded them by such treatment as painting. Maintenance of these materials should be thorough, and if the cost of maintenance is likely to be excessive, a material requiring less upkeep should be substituted.

157. Capital cost and maintenance costs, and therefore durability, are factors which can be balanced in terms of annual expenditure. It is not necessarily true that materials requiring periodic protection are in total more expensive than those requiring no protection.

VERMIN INFESTATION

158. The commonest and most serious form of the infestation of dwellings is that by the bed-bug; this problem faces nearly every urban authority. Infestation is generally thought of in connection with old and dilapidated dwellings, but extensive infestation of new houses has occurred.

159. The bed-bug and the methods of prevention and control of infestation by it have been the subject of two important reports which should be studied by everyone concerned with the erection of dwellings which may become infested.[1]

160. The 1934 report[1] classifies the control of bed-bug infestation (p. 7, section 4) under three headings:

A. The prevention of dissemination of bed-bugs.

B. The destruction of bed-bugs in inhabited and empty houses.

C. The elimination of bed-bug harbourage in new houses.

161. The elimination of bed-bug harbourage (C.) and the possibility that the building may have to be disinfested at some time (B.) should be borne in mind throughout the process of designing.

[1] *Reports on Public Health and Medical Subjects: No. 72 Report on the Bed-bug* (Ministry of Health; published by H.M. Stationery Office, 1934; price 1s. net). *Report of the Committee on Bed-bug Infestation*, 1935–40 (Medical Research Council; published by H.M. Stationery Office, 1942; price 1s. net).

162. The bed-bug feeds on blood, preferably human blood, and mainly at night. When introduced into a dwelling, the bed-bug founds its first colonies in beds, if they are not disturbed by cleaning. As their numbers increase, overcrowding is avoided by the establishment of further colonies, in furniture near the bed, behind pictures and picture rails, in cracks in the walls and so on, the bugs " trekking " to feed at night.

163. Thus there are two degrees of infestation; the less serious, when only the furniture and other belongings of the occupants are infested; and the more serious, when the bed-bugs have obtained a foothold in the fabric of the building. The second aspect presents relatively greater difficulties of disinfestation.

THE ELIMINATION OF BED-BUG HARBOURAGE

164. Practically, it is impossible to guarantee that any form of construction will be free from all cracks and crevices which might provide harbourage for bed-bugs. With care in design, the likelihood of serious infestation can be considerably reduced. It is advised that such simple precautions as the avoidance of paper on the walls, the elimination of wooden picture rails, and the substitution of cement for wooden skirtings " have been successful in their object and very few cases of gross infestation are now met with in the houses where these improvements have been introduced, because the bug is easily observed and checked at a stage before serious spread can occur." [1]

165. It is impossible within the scope of this Report to indicate all the causes of cracks in buildings in detail; the following groups are intended only as indications of the kind of points which will need study:

a. Structural cracks; the result of settlement, deflection, impact, etc.

b. Cracks due to drying shrinkage of materials.

c. Cracks due to thermal movements of materials.

d. Cracks at the junctions of different members or materials—*i.e.* open joints or joints with mouldings or cover members.

e. Cracks between the structure and " built-in " fittings.

f. Cracks round service pipes and conduits.

166. While it is possible to reduce the potential harbourage in any given circumstances by the exercise of forethought, it is impossible to eliminate it; furthermore, this end cannot be considered isolated from the other factors in design. The best solution of any one problem may have to be modified in the light of other conflicting requirements, as, for example, considerations of the thermal insulation of the dwellings, or of sound insulation, or of available materials, may lead to the adoption of a form of construction with greater potential harbourage than a normal " solid " construction would provide. For these reasons, the disinfestation of the dwelling at some future time should be kept in mind at the time of its design.

THE DESTRUCTION OF BED-BUGS

167. In the case of slight infestation, domestic cleanliness is the most efficient method of disinfestation. In Section IV of the 1943 report previously referred

[1] *The Bed-bug: Prevention of House Infestation. A Study for Public Health Purposes*, by Wm. C. Gunn, M.D., D.P.H., Senior Assistant Medical Officer, Public Health Department, Glasgow. (Department of Health for Scotland. Published by H.M. Stationery Office, 1943 ; price 9*d.* net.)

to, Dr. Wm. C. Gunn, M.D., D.P.H., writing on "Domestic Hygiene in the Prevention and Control of Bed-bug Infestation," says "No-one who keeps a clean house need fear its invasion by the bed-bug." Some of the factors to be kept in mind when designing are generous and straightforward planning, giving easy access to all parts; careful design in detail, avoidance of unnecessary lodgment for dust and dirt; adequate natural and artificial lighting of all parts of the dwelling.

168. If serious infestation takes place, chemical methods may be necessary to get rid of the bed-bugs.[1] The chemical disinfestation of dwellings is a difficult undertaking. The ability of the bed-bug to conceal itself in cracks and crevices necessitates the use of fumigants or liquid insecticides, and the choice of these is limited by the combination of qualities which is required: the insecticide should have a high degree of toxicity to the bed-bug at all stages of its development; it should not harm those using it or occupying dwellings treated with it; it should not be inflammable or explosive; it should not harm the structure or contents of the dwellings with which it comes into contact.

169. The use of these fumigants will be made easier if the processes involved have been borne in mind at the planning stage. For example, in the case of the application of heavy naphtha, pre-heating in cold weather and the maintenance of the vapour concentration, implying the effective sealing of all cracks, is necessary. Disinfestation will be simplified if this requirement has been appreciated at the time of detailing the elements, *e.g.* windows; and the use of screens wetted with naphtha (which are hung 3 in. from the walls on light scaffolding) will be facilitated by the straightforward planning of the rooms. It is important, therefore, that the designer should make himself familiar with the different methods: generally, the planning should be simple, rectilinear and providing easy access: fittings and wall linings, if used, should be easily removable, so that, where possible harbourage cannot be avoided, disinfestation is made comparatively easy.

SUMMARY OF DESIGN REQUIREMENTS

170. In some of the foregoing notes on the basic considerations of house design, it has been possible to suggest certain definite, if provisional, standards with which houses should comply. For the convenience of designers, these standards have been collected and are restated in this summary.

171. In the sections covering subjects which are not capable of such evaluation, general recommendations have been made. No attempt has been made to summarise these recommendations, for which the several notes must be consulted.

STRENGTH AND STABILITY

172. DEAD LOADS. The dead load comprises the weight of all walls, partitions, floors, roofs and all other permanent construction in the building. The unit weights of the various materials are given in *British Standard No.* 648.

173. SUPERIMPOSED FLOOR LOADS. Superimposed floor loads comprise all floor loads other than dead loads. Floors for houses of not more than 2 storeys should be capable of supporting a superimposed floor load of 30 lb. per sq. ft. or a load of 240 lb. uniformly distributed on any foot width of slab or floor-board, whichever gives the worse conditions. Beams should be capable of carrying a load of 1920 lb. uniformly distributed. *Note*: Beams, ribs and joists spaced not more than 3 ft. apart may be calculated for slab loading.

[1] See Reports referred to in footnote on p. 36.

174. PARAPETS AND BALUSTRADES. Parapets and balustrades should be designed for a horizontal load of 25 lb. per foot run acting at handrail or coping level.

175. WIND ON VERTICAL SURFACES. The horizontal wind load acting on the vertical surfaces of a building not more than 20 ft. high to eaves should normally be assumed to be 8 lb. per sq. ft., but in the case of buildings situated in especially exposed situations (at the seaside, on the shores of lakes and estuaries, on open moorlands or hill-tops, etc.) the load should be assumed to be 16 lb. per sq. ft. One half of this wind load may be assumed to act as a pressure on the windward face and one half as a suction on the leeward face.

176. In the case of dwellings of normal proportions, where the height does not exceed three times the width, and where the building is stiffened by walls or built-in panels of brickwork or concrete and with cross walls of similar material, it will not be necessary to make calculations for the general stability of the building against wind pressure. For calculation of the stability of external walls, panel fillings and their supports 70 per cent. of the above wind load should be considered to be acting in either direction (inwards or outwards) on all external faces of the building.

177. ROOF LOADING. The following superimposed snow and wind loading should be assumed for roofs:

178. *Flat Roofs.* On flat roofs and on roofs up to 10° pitch a superimposed load (including snow) of 30 lb. per sq. ft. measured on plan In the case of flat roofs of light construction, which may be affected by suction, a negative pressure (suction) of 10 lb. per sq. ft. should be assumed to act over the whole area of the roof.

179. *Sloping Roofs.* i. A snow load of 10 lb. per sq. ft. measured on plan. ii. A negative pressure (suction) on the leeward slope of 8 or 16 lb. per sq. ft. normal to surface. (See para. 175.)

180. Sloping roofs should be capable of resisting the above conditions, i. and ii. singly, or in conjunction.

181. The roof covering (if it can be walked on) and the individual members of the roof framing should be capable of sustaining the following alternative loads:

100 lb. concentrated at any point accessible by means of a ladder.

200 lb. concentrated at any point accessible without a ladder.

MOISTURE PENETRATION AND CONDENSATION

182. Solid walls of permeable materials resist moisture penetration by acting as partial "barriers" or "sponges"; the former are difficult to achieve in practice and defects may result in aggravated water penetration; the latter must eventually fail under prolonged rain.

Monolithic concrete walls depend for their weather resistance upon careful design and a high degree of workmanship. The structure of no-fines concrete diminishes the likelihood of moisture penetration.

Cavity walls depend upon a complete interruption of the capillary paths by an airspace, and precautions must be taken where the airspace is budged.

A damp proof membrane is necessary in solid concrete floors laid directly on the ground on most sites and with many floor coverings. (See Tables I and II, pp. 108–9.)

Condensation is minimised, in the case of "permanent" condensation, by adequate ventilation, thermal insulation, and heating; and, in the case of "temporary" condensation, by using linings of low thermal capacity.

THERMAL INSULATION

183. It is suggested that the following maximum values for heat transmittance coefficients will prove economical:

a. In houses in which apparatus allows of full control over the heat output:

External walls of living room . .	U not to exceed 0·15 B.Th.U./sq. ft./hr./° F.
,, ,, rest of house . .	,, ,, exceed 0·20
Ground floor	,, ,, ,, 0·15
Roof and top floor ceiling . . .	,, ,, ,, 0·20

b. In houses in which the apparatus does *not* allow of full control over the heat output:

External walls of living room . .	U not to exceed 0·20 B.Th.U./sq. ft./hr./° F.
Ground floor	,, ,, exceed 0·15
Roof and top floor ceiling . . .	,, ,, ,, 0·30

SOUND INSULATION

REDUCTION STANDARDS

184. AIRBORNE SOUND:

a. Between the living room in one dwelling and the living room and bedrooms in another, 55 db. reduction.

b. Between the living room and other rooms, excepting service rooms, in the same dwelling, 45 db. reduction.

c. Between other rooms, excepting service rooms, 35 db. reduction.

185. IMPACT SOUND:

Between any room in one dwelling and the living room or bedrooms of a dwelling beneath, 15 phons reduction as compared with a bare concrete floor or 20 phons reduction as compared with a bare timber floor.

FIRE HAZARD

186. a. PERSONAL HAZARD. Linings should preferably be of incombustible materials. Provision should be made against risk of collapse under fire.

187. b. STRUCTURAL HAZARD. Party walls should be of incombustible material and should have a fire resistance of 2 hours as defined in *British Standard Definitions* (*No.* 476). Steelwork, the collapse of which in case of fire might affect the party wall, should be protected so as to have a fire resistance of half an hour.

188. c. EXPOSURE HAZARD. External walls should be of incombustible materials, and roof coverings should preferably be of the materials conforming with the requirements set out in the *Ministry of Health Model By-laws, Series IV.* The table on p. 28 should be followed where applicable.

MAINTENANCE AND DURABILITY

189. See general discussion.

VERMIN INFESTATION

190. See general discussion.

APPENDIX TO PART I

COMPARISON OF DESIRED STANDARDS WITH THE VALUES ACHIEVED BY NORMAL BRICK CONSTRUCTION

191. In the following table, for convenience of reference, the values of the different elements of a normal brick house are compared with the values of the desirable standards, with an indication as to whether they are high or low in relation to the standards.

BRICK HOUSE

ELEMENT	REQUIREMENT	VALUE	DESIRABLE STANDARD	VALUE COMPARED WITH STANDARD
11-in. cavity exterior wall plastered internally (cavity unventilated).	Thermal insulation	0·30 [1]	0·15–0·20	Low
9-in. brick external walls roughcast externally, with plaster on battens (1½ in by 1 in.) (Scottish practice).	Thermal insulation	0·28 [1]	0·15–0·20	Low
9-in solid brick party wall plastered both sides.	Sound insulation [2] Fire resistance [3]	50 db. 6 hrs.	55 db. 2 hrs.	Low Ample
Partitions 2½-in. clinker blocks plastered.	Sound insulation Between living room and other main rooms. Between other main rooms.	 About 35 db. „	 45 db. 35 db.	 Low Adequate
Ground floor: 1-in. (nominal) T. & G. boarding on timber joists, ventilated under, covered with lino.	Thermal insulation	0·35 [1]	0·15	Low
Wood-block floor on concrete laid direct on ground.	Thermal insulation	0·15 [1]	0·15	Satisfactory
First floor: 1¼-in. board on wood joists, ½-in. plaster.	Sound insulation, air-borne	35–45 db.	For flatted dwellings only, 55 db.	For flatted dwellings only, low
	Sound insulation, impact.	Standard	+20 phons	Low

[1] Thermal insulation figures are expressed throughout in terms of "U" the transmittance coefficient (see Part I). A high value of this coefficient means low insulation.

[2] The values given for sound insulation refer throughout to the reduction of *air-borne* noise, except where impact noise is specifically mentioned.

[3] As tested under the standard conditions laid down in *British Standard Definitions* (*No.* 476, 1932).

BRICK HOUSE—*continued*

ELEMENT	REQUIREMENT	VALUE	DESIRABLE STANDARD	VALUE COMPARED WITH STANDARD
First floor: ⅞-in. T. & G. boarding on joists, 3 in. of ashes on ⅞-in. boarding; lath and plaster ceiling. (Scottish practice.)	Sound insulation, air-borne	50 db.	55 db. for flats only	Low
	Sound insulation, impact	+10 phons	+20 phons for flats only	Low
Roof: tiled on battens and felted: plaster ceiling.	Thermal insulation	0·43	0·30–0·20	Low
Roof: slating direct on felt underlay on ⅞-in. sarking and lath and plaster ceiling. (Scottish practice.)	Thermal insulation	0·35–0·30	0·30	Low

PART II. SURVEY OF ALTERNATIVE FORMS OF CONSTRUCTION USED IN THE INTER-WAR PERIOD

192. In the course of the survey of alternative forms of construction used in this country during the period 1918–39, nineteen different systems have been investigated; typical houses were inspected, drawings and other data considered, and discussions held with tenants, and in most cases with promoters, contractors, local authorities, and owners. Generally several examples of each type on more than one site were inspected so that a fair assessment of each system could be made.

193. It is not claimed that this survey is complete. The systems reviewed, however, are representative of the principal approaches to the problems of alternative methods of construction in this country during the inter-war period.

194. It is intended to review systems differing materially in construction from those reviewed here, which come to our notice either in this country or from abroad, and to describe them in a further report.

195. The number of houses of each type are recorded below with their location, date of erection, and details of construction. It should be noted that all houses of one type were not necessarily built alike. Details were altered, sometimes to suit local conditions and sometimes to rectify faults which had developed in earlier prototypes. As a result of the shortage of materials and the necessity for economy, mistakes were sometimes made in the design of conventional roofs and floors which later gave rise to considerable troubles. For instance, in some cases tiled roofs were unlined, the pitch was too low, and the tiles had insufficient lap, resulting in moisture penetration and excessive loss of heat. Moisture penetration also occurred in some cases through badly designed windows, or through faulty junctions between the window frames and the walls. Again, there were cases where the incorrect design of timber ground floors gave rise to trouble from dry rot. As this survey is concerned with "alternative forms of construction," no special mention is made of such defects, unless they are inherent in or directly connected with the novel features of the construction.

SUMMARY OF DESIGN REQUIREMENTS

196. The report on the survey includes an analysis of the efficiency of the non-traditional elements of the houses inspected, with notes on any relevant information obtained during the course of the survey on such subjects as initial cost, cost of maintenance, speed of erection, appearance, and the appeal of the houses to housing authorities and tenants. Comparison is made in most respects with the 11-in. cavity brick wall type of house as being the fairest basis for houses built in the inter-war period, even though the brick house falls below some of the standards now suggested for new design in Part I.

197. Available information on the initial cost, cost of maintenance, and speed of erection of the novel elements of the construction was of a very general and incomplete nature, and inquiries gave somewhat negative results for the following reasons:

INITIAL COST. The information obtained regarding the initial cost of the houses was in all cases in terms of contract prices. In normal times when competition is keen, a comparison of the contract prices with those of brick would give a fair indication of the saving or extra expense incurred by the adoption of a special form of construction. When the houses were built, however, there was little or no competition and the contract prices for all types were approximately the same as for brick houses built at the same time. It is therefore uncertain what relation the contract prices quoted in the report bear to the actual cost of the houses.

MAINTENANCE. Maintenance costs do not include internal decoration in Scotland and cannot therefore be compared with maintenance costs of English houses. They also vary with treatment; for instance, the Weir houses have cost roughly 10*s.* a year more to maintain than brick houses; this average may be expected to diminish as a result of the application of paint harling.

SPEED OF ERECTION. So far as could be ascertained, few records of the numbers of man-hours on site or in factory were kept. Information that can now be given as to the date of commencement and completion is not in itself reliable as an index in the absence of data regarding any delays due to weather conditions or other causes of which account should be taken. Precise information on these items would have been of great value both in assessing the merits of the various systems and in formulating future programmes of house construction. We feel that steps should be taken to ensure that in the future data of the kind that are now lacking shall be collected and put on permanent record so that they may be available for future guidance. Such data would moreover form an invaluable complement to laboratory research.

198. It has been found convenient to group certain types of construction with similar characteristics and to consider them under one heading.

CONCRETE HOUSES

199. Concrete was used extensively as an alternative to brickwork during the inter-war period. Many different systems of concrete walling were evolved, but only typical examples were inspected during the survey. These have been considered under groups which illustrate basic differences in type.

SINGLE LEAF WALLS, CAST *IN SITU* IN REMOVABLE FORMS

THE NO-FINES CONCRETE HOUSE

200. By " no-fines " or " open-textured " concrete is meant concrete made with aggregate from which all the fine material has been removed. A number of houses have been built in England and Scotland with walls, poured *in situ*, of this type of concrete.

201. No-fines concrete (clinker aggregate) houses as follows were developed by Corolite Construction Co., Ltd. (Manchester, Edinburgh, Willesden, etc.), and by Unit Construction Co. and Wilson Lovatt and Sons, Ltd. (Liverpool):

NO. OF HOUSES	SITUATION	DATE OF COMPLETION	OWNER
150	Liverpool	1927	Liverpool Corporation
580	Manchester	1927	Manchester Corporation
50	Edinburgh	1923	Edinburgh Corporation
—	Willesden and other sites in England and Scotland	1927	Willesden Corporation and other local authorities

The Manchester, Liverpool and Edinburgh houses have been inspected.

202. No-fines concrete (heavy-weight aggregate) houses as follows were developed and built by the Scottish Special Housing Association:

NO. OF HOUSES	SITUATION	DATE OF COMPLETION	OWNER
222	Carluke	1940	Scottish Special Housing Association
272	Tannochside	1941	
36	Holytown	1942	
209	Dunfermline	1941	Admiralty
162	Rosyth	1942	

All the schemes have been inspected.

203. EXTERNAL WALLS. The walling material was of two types:

a. No-fines concrete with clinker aggregate. The external walls were 9 in. thick, rendered externally and plastered internally. The party wall was also 9 in. thick and partitions 2 in. and 4 in. thick. Except at Liverpool a proprietary system of shuttering was used (wooden posts and steel plates) and the walls were poured in two lifts. The first floor and roof were in some cases of 3 in. reinforced clinker concrete: in others, a timber-framed roof covered with tiles was used.

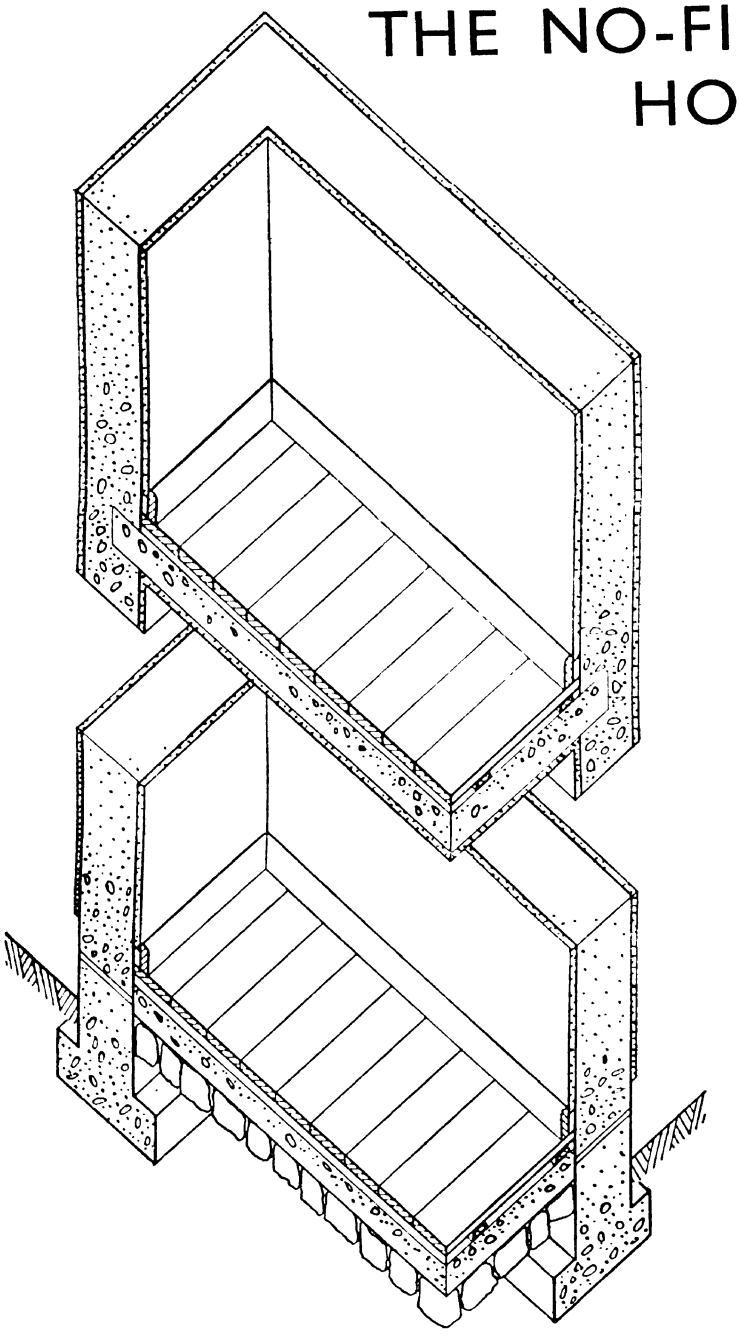
b. No-fines concrete, with whinstone, gravel or blast furnace aggregates. The external walls and party wall were 8 in. thick and the partitions were 4 in. thick. The external walls were rendered externally and plastered internally. A proprietary system of shuttering was used and the walls (of a two-storeyed house) were poured in two lifts.

204. PARTY WALLS AND PARTITIONS. The party walls were in each case similar to the external walls. The partitions were in some cases 4 in. and in others 2 in. thick.

205. FLOORS AND ROOFS. Joisted and boarded floors and timber-framed roofs covered with slates or tiles were used in most houses. In some cases, however, reinforced concrete roofs with built-up bitumen roofing and reinforced concrete floors were adopted.

206. STRENGTH AND STABILITY. Nothing was observed on any of the sites to suggest that the walls were inadequate in respect of strength and stability. No direct test data are available concerning the strength of no-fines concrete walls, but consideration of the loads carried by walls of houses of not more than 3 storeys suggests that the cube strength of the concrete should not be less than 200 lb. per sq. in. at 7 days and 350 lb. per sq. in. at 28 days, and that the thickness of walls should be the same as would be used normally for brick houses. (See Notes on Recommendations for the use of no-fines concrete.)

THE NO-FINES HOUSE



NO-FINES CONCRETE POURED IN SITU WITH EXTERNAL AND INTERNAL RENDERING. FLOOR AND FOUNDATIONS OF DENSE CONCRETE ON HARDCORE

207. RESISTANCE TO MOISTURE PENETRATION. Tests at the Building Research Station have indicated that rendered panels of no-fines concrete 9 in. thick are not subject to rain penetration. Experience over 16–18 years of houses having clinker concrete walls 9 in. thick treated externally with roughcast confirm this result. 8-in. walls of hard aggregate treated with roughcast have been equally satisfactory over a period of two years. Leakages have occurred, but it is considered that these are due either to bad workmanship—for example, in pointing window frames—or to lack of appreciation of the necessity for preventing the entry of water into the body of the wall at such points as openings or through the use of unsuitable renderings. On one site some penetration of the walls occurred through cracks in the rendering caused by the use of unsound clinker.

208. THERMAL INSULATION. The computed coefficient of heat transmission for 8-in. walls of heavy-weight aggregate is between 0·43 and 0·46. No complaints were made of condensation troubles on any of the sites, but a few tenants stated that the houses were "rather cold."

209. The computed coefficient for clinker aggregate walls 9 in. thick is 0·29. This is slightly better than for an unventilated 11-in. cavity brick wall.

210. SOUND INSULATION. The mass per unit area of no-fines concrete party walls where a heavy-weight aggregate is used is not very different from that of a 9-in. brick wall. The sound insulation provided was therefore approximately the same. Where light-weight aggregate was used the sound insulation provided was inferior. The partitions were satisfactory in respect of sound insulation.

211. FIRE HAZARD. The construction is comparable, in respect of fire hazard, with normal brick houses, and is therefore satisfactory.

212. MAINTENANCE AND DURABILITY. Provided that the aggregate was sound, that there was good design of constructional detail of openings, etc., and that a suitable rendering was used, walls built of no-fines concrete were durable and maintenance costs were low.

213. VERMIN INFESTATION No-fines concrete houses were not more prone to vermin infestation than brick houses. In the houses built with dense aggregate, the absence of cracks in the plastering, probably a result of the good key provided by no-fines concrete, was worthy of note; such freedom from cracks should help to prevent infestation. It must be recognised, however, that if infestation were to take place through cracks in the plastering, disinfestation might be troublesome on account of the cellular nature of the walls.

214. GENERAL INFORMATION. Little reliable information was available concerning the costs of no-fines houses. It would appear that there was little difference between houses built with 8-in or 9-in. no-fines concrete walls and those built with 11-in. cavity brick walls. This opinion was to some extent confirmed by information received from a firm of contractors, who stated that, in 1920-24, no-fines concrete walls with external roughcast cost approximately the same as 11-in. cavity walls fair faced externally. However, it was also stated that under normal conditions the latter were slightly cheaper than no-fines walls.

215. No separate maintenance cost figures were available, but all housing authorities indicated that maintenance costs were not greater than for brick houses.

216. With regard to speed of erection, the general impression formed was that this depended largely on the efficient organisation of the work, but that in general no-fines concrete walls were built at least as quickly as brick walls.

217. As with other types of poured concrete construction a large percentage of unskilled men can be employed.

218. The appearance of no-fines concrete houses differs in no way from that of roughcast brick houses.

219. There has been considerable experience in the inter-war period of house building in no-fines concrete. Investigations into some features of this material are continuing, but it is established that it is a satisfactory alternative, if properly used, to brickwork. Recommendations on the use of no-fines concrete are incorporated in this report (Appendix, p. 140).

220. There have been some complaints that houses of no-fines concrete are cold, and it should be noted that the thermal insulation of a wall of no-fines concrete of dense aggregate is similar to that of a solid brick wall. Additional insulation is necessary if an 8-in. no-fines wall of heavy aggregate is to achieve the standard of an 11-in. cavity brick wall in this respect.

221. With a high degree of organisation and supervision, satisfactory walling of no-fines concrete can be constructed rapidly, and a high proportion of labour inexperienced in the building industry can be employed; but no great reduction of cost, as compared with brickwork, can be expected.

SINGLE LEAF WALLS WITH INSULATING LINING CAST *IN SITU* IN REMOVABLE FORMS

222. Only one type of concrete house with an internal permanent shuttering of insulating material has been inspected. They were built as follows:

NO. OF HOUSES	SITUATION	DATE OF COMPLETION	OWNER	REMARKS
52	Tullos Housing Estate, Aberdeen	1939	Aberdeen City Corporation	A few houses were left incomplete at the outbreak of war.
68	Kaimhill Housing Estate, Aberdeen	1939		

223. EXTERNAL WALLS. The external walls were of cast *in situ* concrete composed of 1 part cement: 2 parts sand: 4 parts graded granite aggregate, the thickness of the concrete being 7 in. for the front and back walls and 8 in. for the gable walls. The reinforcement consisted of $\frac{1}{4}$-in. rods set vertically and horizontally at 3-ft. centres in the centre of the concrete walls with extra reinforcement as necessary over door and window openings. Normal timber formwork was used and wood-wool slabs 1 in. in thickness were placed in the formwork before pouring the concrete to form an internal wall lining. The total thickness of the external walls was thus 8 in. and 9 in. The walls were harled (roughcast) externally, the first coat being 1:2 cement and sand, the second 1:3 cement and sand, and the third 1:2 cement and fine granite chippings. The first was allowed to dry before the second was applied, but the third, which was thrown or "dashed" on, followed the second immediately.

224. PARTY WALL. The party wall was built of precast concrete blocks 6 in. thick jointed in cement mortar; it was tied to the chimney breast with hoop-iron ties.

225. CHIMNEY BREASTS. The chimney breasts were of concrete cast *in situ* with fireclay flue linings cast in position. In other respects the construction was conventional, though generally the standard of building was higher than is usual in most other districts.

226. STRENGTH AND STABILITY. The strength and stability of the walls was adequate.

227. RESISTANCE TO MOISTURE PENETRATION. No moisture penetration ha occurred.

228. THERMAL INSULATION. The external walls with the wood-wool internal lining and external harling had a computed coefficient of heat transmission of ·25, so that the insulation was better than that provided by an unventilated and rendered 11-in. brick cavity wall.

229. SOUND INSULATION. The party wall provided slightly less resistance to air-borne sound than does a 9-in. brick wall.

230. FIRE RESISTANCE. The construction is comparable with normal brick and timber houses and, in respect of fire hazard, is therefore satisfactory.

231. MAINTENANCE AND DURABILITY. The durability of the walls was satisfactory.

232. Solid concrete walls commonly develop shrinkage cracks and are frequently deficient in respect of thermal insulation. Damp penetration and condensation are thus often experienced with this form of construction. In the houses inspected reinforcement was provided to reduce the tendency for the development of major shrinkage cracks and an insulating wall lining was provided.

233. VERMIN INFESTATION. In respect of vermin infestation and disinfestation there is no difference between these and brick houses.

234. GENERAL INFORMATION. The houses were rather more costly to erect than were brick houses of similar design built at the time. The costs were £594, 6*s*. 4*d*. and £562, 10*s*. 5*d*. for the concrete and similar brick houses respectively, which represents 9¾*d*. and 9⅜*d*. per cu. ft.

235. Maintenance costs were not expected to exceed those for brick houses.

236. There was no saving in craftsmen's labour in building these houses, since with timber formwork, the saving in bricklayers' labour was offset by the extra carpenters' labour involved.

237. In appearance there was no difference between the concrete and brick houses on the same estates. The tenants and local authorities were satisfied with the houses in all respects.

238. To summarise, satisfactory houses have been built with this form of walling, which is a useful alternative when bricklayers are not available.

SINGLE-LEAF WALLS, CAST *IN SITU* IN PERMANENT SHUTTERING

THE UNIVERSAL HOUSE

239. The Universal system of house construction was developed by the Universal Housing Co., Ltd., and houses of this type were built as follows:

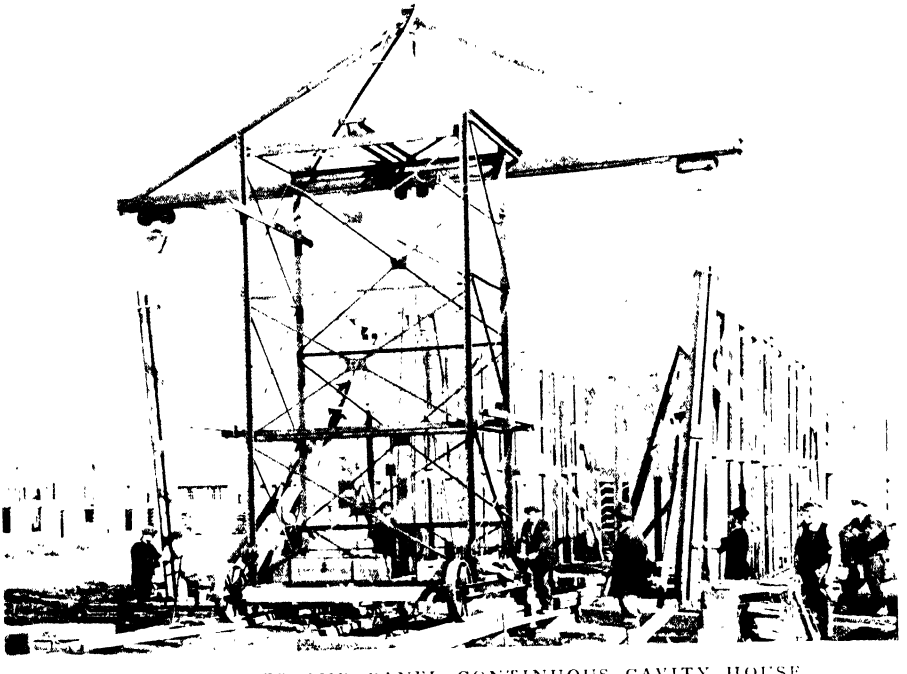
NO. OF HOUSES	SITUATION	DATE OF COMPLETION	OWNER
60*	Rickmansworth	1925	Rickmansworth U.D.C.
294*	Newton Abbot	1926	Newton Abbot U.D.C.
100	Liverpool	1927	Liverpool Corporation
130*	Torquay	1927	Torquay Corporation
40*	Ruislip	1928	Ruislip U.D.C.
128*	Tunbridge Wells	1928	Tunbridge Wells Corporation
120	Beckenham	1927	Beckenham U.D.C.
200	Isle of Man, etc.	1935	—

The schemes marked with an asterisk have been inspected.



THE DUO-SLAB HOUSE IN CONSTRUCTION

See p. 56



THE BOOT PIER AND PANEL CONTINUOUS CAVITY HOUSE

See p. 58



THE WINGET PIER AND PANEL HOUSE IN CONSTRUCTION

See p. 60



TYPICAL LIGHT STEEL FRAME CONSTRUCTION

See pp. 73-80

240. EXTERNAL WALLS. The external walls consisted of a reinforced concrete core faced both sides with asbestos cement sheets used as permanent shuttering, the total thickness was $6\frac{3}{4}$ in.

241. Pressed steel-channel stanchions ($3\frac{1}{2}$ in.$\times$2 in. of 15 gauge) were set up at 4-ft. centres, and to these were wired the inner and outer sheets of asbestos cement. The stability of the wall did not depend upon these stanchions: their chief function was to support the permanent shuttering and the roof framing before the concrete wall was poured. They also provided a fixing for the angle tie at first floor level, which carried the floor joists.

242. In addition to the steel stanchions, horizontal reinforcement was provided by means of $\frac{5}{16}$-in. rods at 6-in. centres. These rods were threaded through holes in the webs of the stanchions.

243. The external facing of asbestos cement was composed of channels 1 ft. high $\times$8 ft. wide and of $\frac{3}{16}$-in. thick material. The inside face of these channels was coated with bituminous material, and had practically no adhesion to the concrete. In the earlier houses, the external channel sections were mitred at the quoins: later, special sections with return ends were used in this position.

244. The internal lining was of flat asbestos cement sheets, 8 ft. high$\times$4 ft. wide and $\frac{3}{16}$ in. thick.

245. Wood cover fillets were used to cover the joints of the internal sheeting; the external joints were pointed in cement mortar.

246. In the earlier houses a clinker concrete was used, but in later houses a concrete made with a mixture of gravel and clinker was used owing to the difficulty experienced in filling the walls with the earlier mix. The mix was nominally 1:6 (cement to aggregate, the latter being composed of approximately equal volumes of clinker and gravel) and was placed semi-dry. The concrete filling was placed in lifts of 1 ft. (one channel section).

247. PARTY WALL. The party wall was of similar construction to the external walls, but was $7\frac{1}{2}$ in. thick. The facings on both sides were flat asbestos cement sheets.

248. PARTITIONS. The partitions on the ground floor were of plastered clinker slab walling. The first floor partitions were of wood-framing lined both sides with asbestos cement sheets.

249. CHIMNEY BREASTS. The chimney breasts and stacks were of precast clinker concrete blocks.

250. The rest of the construction was conventional, and varied in detail on different sites.

251. STRENGTH AND STABILITY. No calculations have been made by the Committee, but it is considered that, provided workmanship is reasonably good, the walls are sufficiently stable for two-storey houses.

252. RESISTANCE TO MOISTURE PENETRATION. Damp penetration through the walls was a major problem. It apparently occurred mainly through shrinkage cracks in the horizontal and vertical joints of the external asbestos cement sheets, although the latter in a large number of cases cracked vertically at the centre and thus accentuated the trouble. Other vulnerable points were the joints between the external sheets and window frames, and at the mitred quoins of the sheets. It was stated that poor workmanship in pouring the wall concrete resulted in the presence of voids behind wall linings.

253. THERMAL INSULATION. When dry, and filled with clinker concrete, the walls are computed to have a thermal transmission coefficient of 0·29, *i.e.* slightly

better than that of an unventilated 11-in. brick cavity wall. The thermal insulation provided by the roof and ceiling is 0·43. Condensation occurred on external walls and upstairs ceilings.

254. SOUND INSULATION. The mass per unit area of the party walls is approximately one-half of that of a 9-in. brick wall, so that the sound insulation of the party walls is inadequate. The upstairs partitions of wood-studding lined with asbestos cement sheets would not offer an insulation equivalent to that of the more conventional plastered breeze block partition.

255. FIRE HAZARD.

a. *Personal and Exposure Hazards.* The construction is comparable with normal brick and timber houses, in respect of personal and exposure hazard, and therefore satisfactory, except that asbestos cement stud partitions are apt to shatter.

b. *Structural Hazard.* The actual construction of the party wall was adequate to prevent the direct spread of fire from one house to the next, but as it was not carried up above the first floor ceiling there was no barrier to the spread of fire once it had reached the roof space. This was unsatisfactory.

256. VERMIN INFESTATION. Bug infestation has not been more prevalent in these houses than in those of normal construction. The disinfestation of affected houses has been difficult.

257. MAINTENANCE AND DURABILITY. Various factors contributed to the high cost of maintenance on several sites, notably repairs made necessary by the cracking of the external asbestos cement sheets and leakage through the joints which resulted in dampness and, in some cases, decay of ground floors. Although the possibility of corrosion of the steel stanchions following moisture penetration cannot be disregarded, there was no evidence of serious trouble from this source on any of the sites, and the promoters claim that the stanchions are not essential for purposes of strength and stability but have the primary function of supporting the internal and external asbestos cement wall linings, during construction.

258. GENERAL INFORMATION. Generally the initial cost of Universal houses was slightly lower than comparable brick houses erected at the same time. The cost of maintenance was higher than that of brick houses.

259. The original form of this construction cannot be regarded as having been satisfactory. At the same time, it is fair to point out that the construction adopted was a useful and original contribution to the problem of providing houses rapidly with labour inexperienced in normal building methods, and that the defects which developed can probably be overcome in future building by modification of the original constructional details. Indeed, some satisfactory modifications were introduced into the later houses.

260. In the light of their experience with the houses inspected the promoters have developed an improvement of their system which is now under consideration.

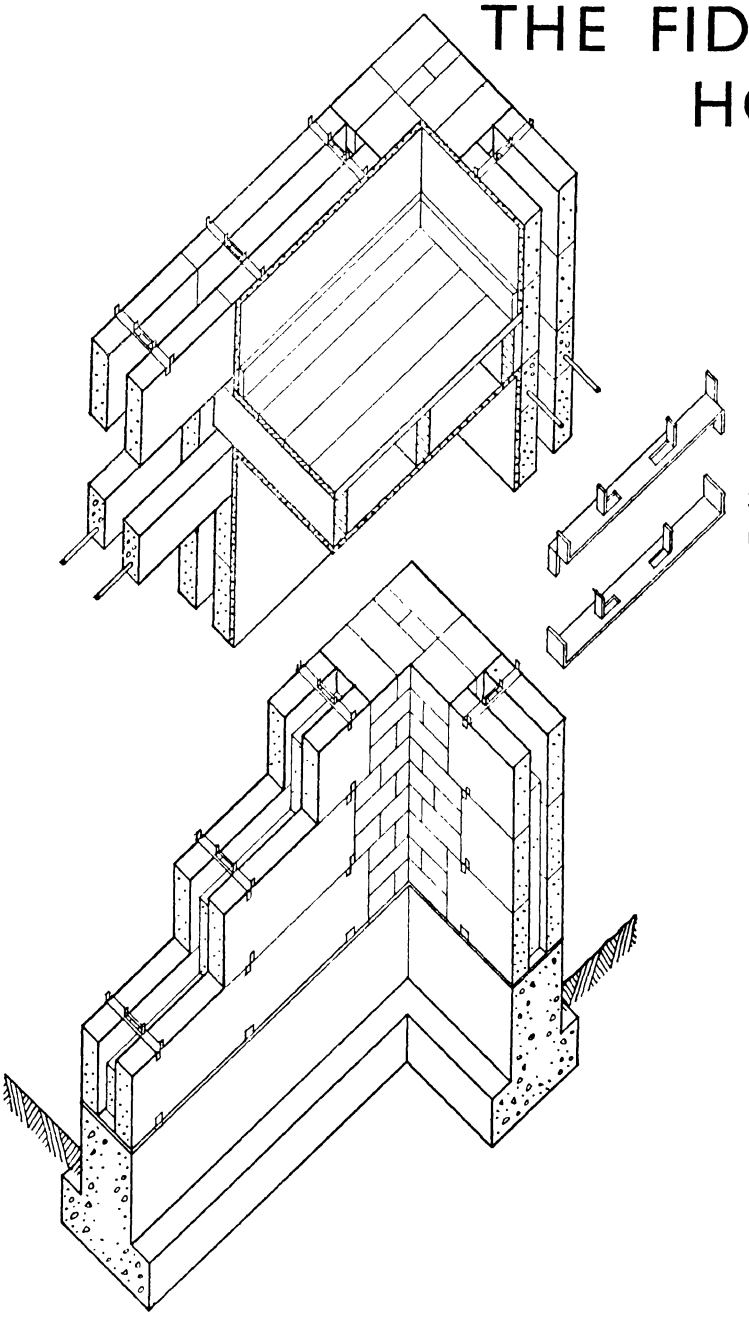
THE FIDLER HOUSE

261. Houses of this type were built at the following places:

NO. OF HOUSES	SITUATION	DATE OF COMPLETION	OWNER
890*	Becontree	1926	London County Council
1000*	Watling	1926	
20	Downham	1926	Lewisham M.B.C.
250	Hayes	1926	Hayes and Harlington U.D.C.

The schemes marked with an asterisk have been inspected.

THE FIDLER HOUSE



CAVITY WALL OF BREEZE SLABS HELD BY METAL CLIPS AND THE CAVITY FILLED WITH CONCRETE. INTERNAL FACE PLASTERED BRICK QUOINS. UPPER FLOORS SUPPORTED ON REINFORCED CONCRETE BEAMS

262. EXTERNAL WALLS. The external walls consisted of two leaves of clinker concrete slabs, each 2½ in. thick (mixed in the proportion of 1 part of cement to 8 parts of clinker by volume) which were used as permanent shuttering for a cast *in situ* core of 1:6 ballast concrete 4 in. thick. The clinker concrete slabs were spaced and held together by light steel wall ties of a special design and built without mortar jointing. The walls were roughcast externally and plastered internally. The ends of the ties projecting beyond the face of the walls were removed before roughcast was applied.

263. In early examples wooden profiles were erected at the main quoins to ensure regular courses and perpendicular walls, but as it was found difficult to maintain these plumb and true, they were eventually dispensed with and the quoins were finally built of brickwork. It was also found necessary to level up the walls to receive floor joists, and this was done with a few courses of brickwork and, in some cases, with a string course of reinforced concrete which acted as a tie for the structure.

264. PARTY WALLS. In a few instances only, the party wall in the roof space was built with the Fidler system, otherwise normal 9-in. brickwork was used.

265. The rest of the construction was conventional.

266. STRENGTH AND STABILITY. The walls were adequately strong and stable.

267. RESISTANCE TO MOISTURE PENETRATION. No moisture penetration through the walls has been reported or observed.

268. THERMAL INSULATION. The computed coefficient of heat transmission for Fidler walls is 0·25, which compared favourably with that for an unventilated 11-in. cavity brick wall.

269. SOUND INSULATION. Most party walls were of 9-in. solid brick construction. Even in those cases where part of the walls was built with the Fidler system the resistance to air-borne noise transmission would be about the same as for a 9-in. wall built entirely in brickwork.

270. The partitions are of normal construction and the sound reduction factor can therefore be considered adequate.

271. FIRE HAZARD. The construction is comparable with normal brick and timber houses in respect of fire hazard and therefore satisfactory.

272. MAINTENANCE AND DURABILITY. The walls can be considered adequately durable. Some shrinkage cracking occurred in the longer blocks of houses, notably where expansion joints were provided, and under windows. The cracks were not serious; they did not appreciably detract from the appearance of the houses, nor did they permit water penetration.

273. Soon after the first few houses were completed the steel-wall ties which were bent over the external face of the precast clinker slabs corroded and the consequent expansion resulted in spalling of the applied roughcast. When it was found that metal ties (which are only intended to hold the slabs together until such time as the concrete filling should set) rusted, the ends of the ties were cut off before rough casting was done, and this practice got over the difficulty. No alteration in the design or material of the ties was required, so long as the part of the tie showing externally was cut off before rough casting was proceeded with.

274. No trouble due to the use of unsound clinker aggregate has been experienced, but with this construction, as with other constructions of concrete, the soundness of aggregates should be ensured.

275. VERMIN INFESTATION. There is no difference between these houses and normal brick houses in respect of vermin infestation and disinfestation.

276. GENERAL INFORMATION. Observations made during the survey of the Fidler houses indicated that they were satisfactory both to tenants and local authorities. The houses were similar in appearance to roughcast brick houses.

277. It appears that the initial cost of Fidler houses was about 5 per cent. more than brick houses with similar accommodation, while maintenance costs were about the same. There was no evidence that Fidler houses were built more speedily than brick houses, but there was a saving in craftsmen's labour.

CAVITY WALLS, CAST *IN SITU*

THE EASIFORM HOUSE

278. The Easiform system of house construction was developed by J. Laing and Son, Ltd.

279. The first Easiform houses were built with solid concrete walls, cast *in situ*, 8 in. thick; a special form of standardised wood shuttering was used, and the concrete was of the no-fines clinker type. Several hundreds of these houses were built at Hereford, Wrexham and South Wales.

280. The later type of Easiform house was built with walls of cavity construction; and it is to houses of this developed type that this report refers. They were built in the following places:

NO. OF HOUSES	SITUATION	DATE OF COMPLETION	OWNER
294	Exeter	1928	Exeter Corporation
862	Eltham	1928	Woolwich Corporation
600	Gosport	1928	Gosport Corporation
350	London	1928	London County Council

281. The Exeter and Eltham schemes have been inspected.
The above are the largest schemes, but a number of small ones have been built elsewhere.

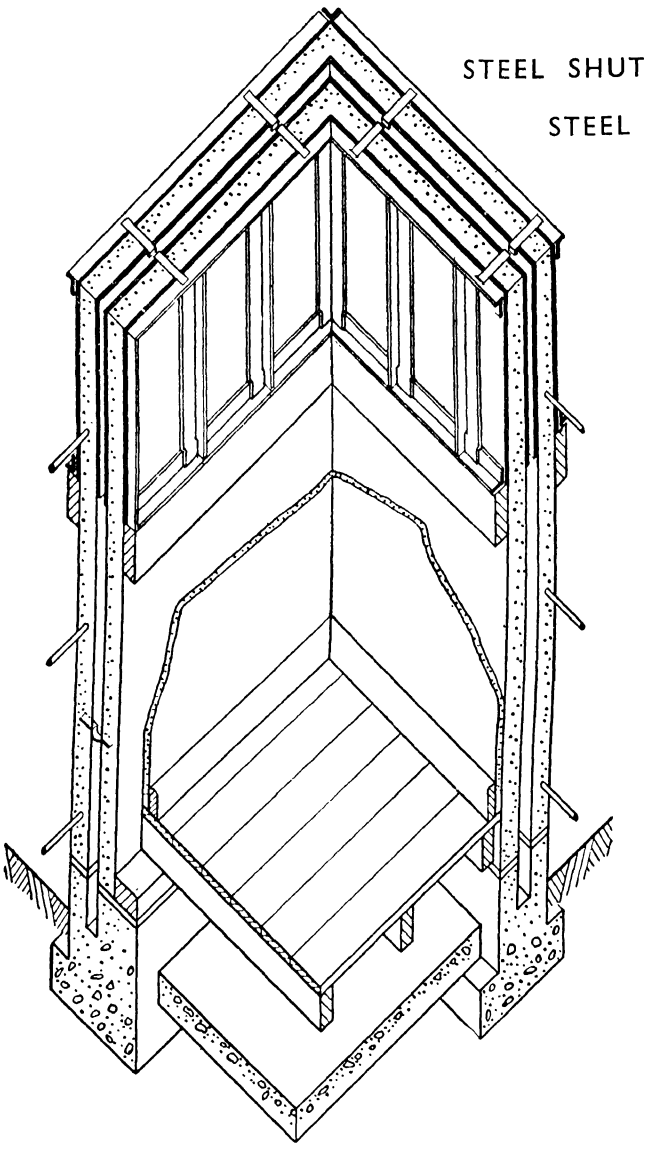
282. EXTERNAL WALLS. The external walls were of concrete (poured *in situ*) consisting of two leaves in cavity construction. The external leaf was 3 in. thick of lightly reinforced gravel concrete. The mix was 1:6, and the reinforcement consisted of ½-in. rods (horizontally) at 2-ft. centres. The internal leaf, also 3 in. thick, was of clinker concrete (1 : 6). The leaves were separated by a 2-in. cavity; and wall ties, at normal spacing, connected the two leaves. The external finish was a one-coat roughcast. A special system of standardised steel shuttering was used. Four types of houses were built in this system.

283. PARTY WALLS. The party walls were of poured clinker concrete, 8 in. thick. The chimney breasts were also of clinker concrete, the flues being formed with temporary tubular steel cores around which was poured ballast concrete to form a lining.

284. PARTITIONS. The partitions were of clinker concrete, 3 in. thick.

285. The rest of the construction was conventional.

THE EASIFORM HOUSE



CAVITY WALL OF REINFORCED CONCRETE EXTERNALLY (ROUGHCAST) AND CLINKER CONCRETE INTERNALLY (PLASTERED). SPECIAL SYSTEM OF STEEL SHUTTERING

THE BOSWELL HOUSE

286. The Boswell system of house construction was developed by M. A. Boswell and Co., Ltd., and houses of this type were built as follows:

NO. OF HOUSES	SITUATION	DATE OF COMPLETION	OWNER
1050	Wolverhampton	1928	Wolverhampton Corporation
1370	Birmingham	1928	Birmingham Corporation
1500	Liverpool	1928	Liverpool Corporation

The Wolverhampton and Birmingham schemes have been inspected.

287. EXTERNAL WALLS. Precast concrete columns of angle section were erected at the quoins of pairs of houses. These formed permanent profiles for the pouring of the walling, which was formed with metal shuttering. The precast columns were reinforced and were of 1 : 2 : 4 mix, with stone aggregate.

288. The walls consisted of two leaves of clinker concrete, each 3 in. or 3½ in. thick, separated by a 2-in. or 3-in. cavity. The mix was 1 : 2 : 4 (cement: sand: clinker) and was placed semi-dry.

289. The cavity was interrupted at 2-ft. 6-in. centres (horizontally) by concrete, forming wall ties. These ties were staggered in alternate courses. The walling was connected to the angle piers by steel ties; in some cases these consisted of projections of the (horizontal) stirrups of the reinforcement of the piers; in other cases, longer ties were specially inserted. The walls were lightly reinforced.

290. The walls were finished externally with a roughcast; internally they were plastered.

291. PARTY WALL. The party wall and chimney breasts were of the same construction as the external walls. The flues were formed in fireclay pipes.

292. The rest of the construction was conventional.

EFFICIENCY OF CONCRETE HOUSES WITH CAVITY WALLS CAST *IN SITU*

293. STRENGTH AND STABILITY. There is no reason to question the strength and stability of the external walls of the Easiform house. With regard to the Boswell house, on one site especially, and to a lesser extent on another, expansion took place to an extent which in some cases raised doubts about the stability of the walls. On other sites where sound clinker was used the walls appear to be of adequate strength.

294. RESISTANCE TO MOISTURE PENETRATION. There was no evidence of moisture penetration to the inner faces of the walls of either type, even in the case of those Boswell houses in which cracking of the outside walls was serious.

295. THERMAL INSULATION. The computed coefficient of heat transmission for Easiform walls is 0·29, that for Boswell walls (both leaves clinker concrete) is 0·24. Both compare favourably with 11-in. cavity brick walls in this respect.

296. SOUND INSULATION. The party walls of both types provided only slightly less resistance to air-borne sound than does a 9-in. brick wall. No complaints were made. The sound reduction factor of partitions of about 40 db. was satisfactory.

297. FIRE HAZARD. The construction is comparable with normal brick and timber houses in respect of fire hazard and therefore satisfactory.

298. With some clinker concretes containing a high proportion of combustible material there is a risk of ignition when they are used in chimney construction. Provided the method of construction used in forming the flues ensures that these are completely lined with dense concrete this risk is negligible.

299. MAINTENANCE AND DURABILITY. Easiform houses should be durable. Maintenance costs were low and were largely restricted to making good internal shrinkage cracks. Some cracking occurred in the outer leaf of the walls, particularly under and over window openings, and in the roughcast on the lines of the bitumen felt expansion joints. Such cracks were, however, not serious. The use of unsound clinker in the case of the Boswell house caused considerable trouble on two sites. Otherwise there is no reason to doubt the durability of these houses.

300. VERMIN INFESTATION. There was no difference between either of these types and normal brick houses in respect of vermin infestation and disinfestation.

301. GENERAL INFORMATION. The difference in cost of these types and brick houses having similar accommodation was slight. Maintenance costs for some Boswell houses proved high as a result of the trouble with unsound clinker. Those for Easiform and for the Boswell where sound aggregate was used were said to be about the same as for brick houses.

302. Local authorities and builders stated that both types can be built more rapidly than normal brick houses and with a high proportion of unskilled and semi-skilled labour, but there are no accurate records to bear this out.

303. The appearance of both types was similar to rendered brick houses built at about the same time.

CAVITY WALLS CONSISTING OF PRECAST CONCRETE SLABS WITH CONCRETE PIERS

THE DUO-SLAB HOUSE

304. The Duo-Slab system of construction was developed by Sir Edwin Airey, and houses of this type were built as follows:

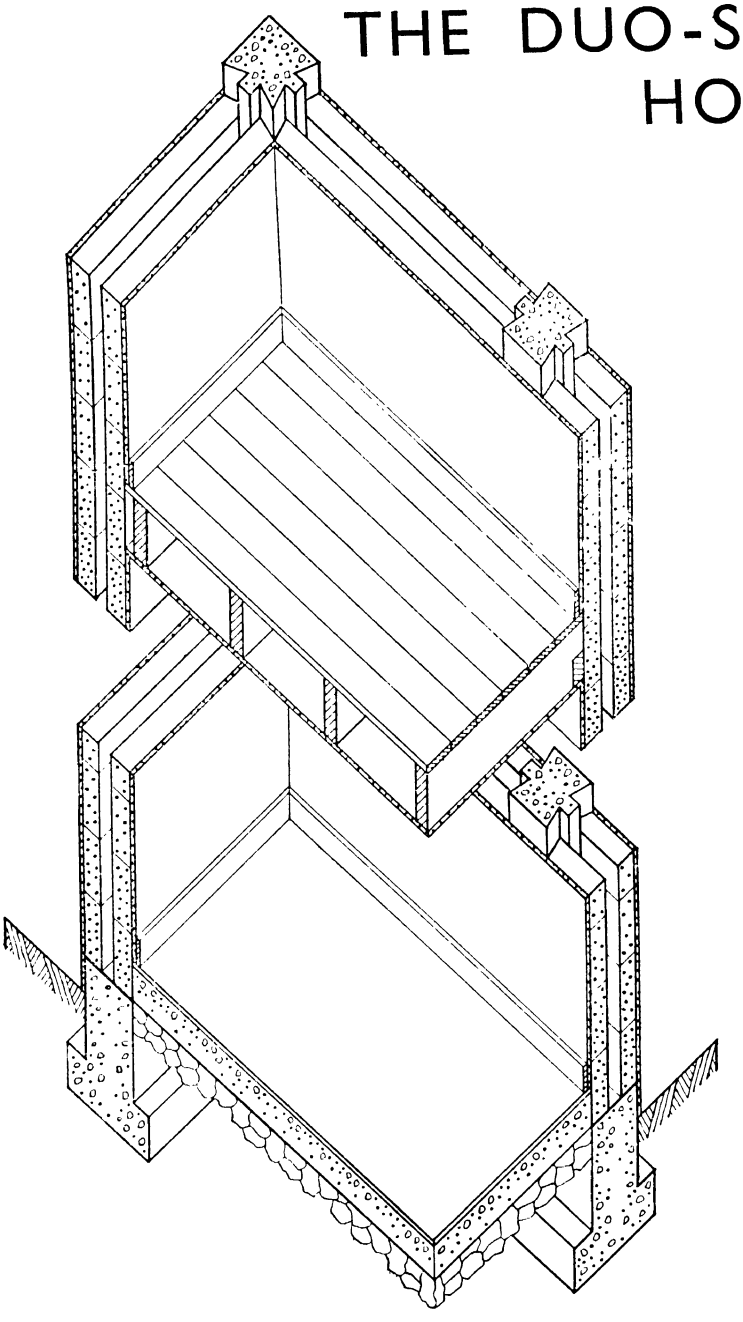
NO. OF HOUSES	SITUATION	DATE OF COMPLETION	OWNER
382	Liverpool	1922	Liverpool Corporation
1600	Leeds	1923	Leeds Corporation
311	Newcastle-on-Tyne	1923	Newcastle-on-Tyne Corporation
1608	Edinburgh	1925	Edinburgh Corporation
250	Swansea	1925	Swansea Corporation
100	Grays Thurrock	1924	Grays Thurrock Corporation

305. EXTERNAL WALLS. The external walls consisted of concrete piers with an infilling of precast clinker concrete slabs forming a cavity wall of total thickness of 8 in. rendered outside and plastered inside.

306. The piers were of unreinforced concrete, poured *in situ*. They were spaced at 4-ft. centres. The mix was 1 : 6 with a clinker aggregate. They were poured as the wall rose.

307. The precast concrete slabs were made with clinker aggregate with ends splayed to provide attachment to the piers. They were about 3 ft. 3 in. long × 8 in. high × 3 in. thick. They were laid without mortar joints, and the two leaves were spaced with wooden distance strips the width of the cavity.

THE DUO-SLAB HOUSE



CAVITY WALLS OF PRECAST CLINKER CONCRETE SLABS. CONCRETE PIERS POURED IN SITU. TIMBER JOIST FLOOR ON WALLPLATES BOLTED TO INNER SKIN

308. The piers were shuttered with timber members, wired together. The external and internal faces were flush with the wall surfaces. The walling slabs were slid into position and held by the shuttering. The end of the slabs, together with the distance strips, formed the shuttering to the sides of the piers. On the shuttering being struck, the slabs were held in the concrete pier by their splayed ends.

309. PARTY WALLS. The party walls were of similar construction to that of the external walls. The chimneys were built in brickwork before the walling was erected.

310. PARTITIONS. The partitions were of 3-in. clinker concrete slabs, with *in situ* piers of the same thickness.

311. The rest of the construction was conventional, and varied in detail on the different sites.

THE BOOT PIER AND PANEL CONTINUOUS CAVITY HOUSE

312. The Boot Pier and Panel Continuous Cavity House system of house construction was developed by Henry Boot and Sons, Ltd., and houses of this type were built as follows:

NO. OF HOUSES	SITUATION	DATE OF COMPLETION	OWNER
1500	Liverpool*	1928	Liverpool Corporation
1000	Sheffield*	1926	Sheffield Corporation
1108	Bradford*	1928	Bradford Corporation
546	Glasgow	1929	Glasgow Corporation
1500	Leicester	1927	Leicester Corporation
500	Dundee	1927	Dundee Corporation
908	Birmingham	1926	Birmingham Corporation
700	London	1930	London County Council
500	Hull	1929	Hull Corporation

313. Houses on the sites of some of the larger schemes marked with an asterisk have been inspected. Less detailed inspections have also been made of the L.C.C. estate at Castelnau, and at Hull.

314. EXTERNAL WALLS. The external walls consisted of piers and infilling panels, forming a cavity wall. The overall thickness was 8 in.

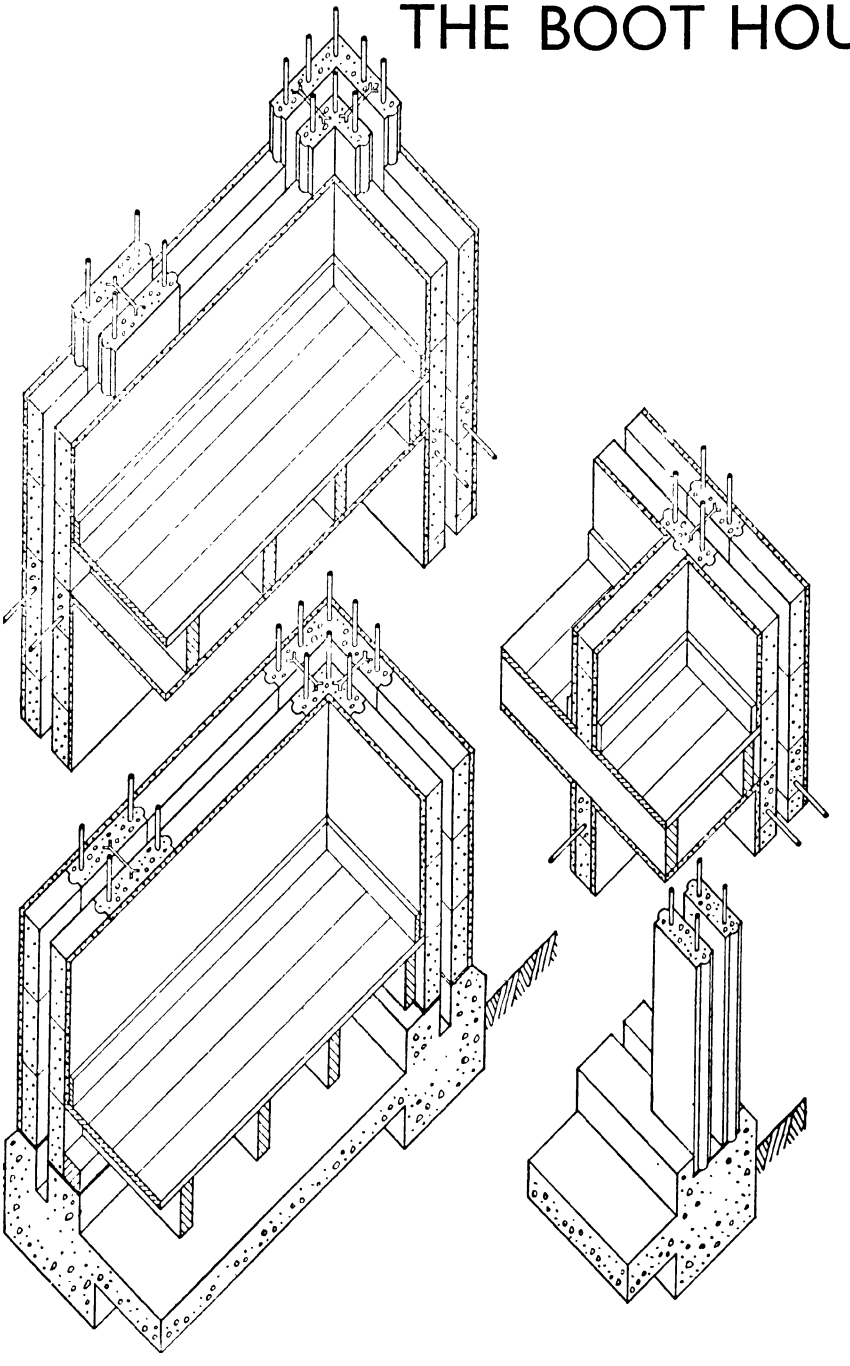
315. The piers were spaced at about 3-ft. centres. They consisted of two precast concrete units, 3 in. thick, spaced 2 in. apart and connected with ties. The concrete foundations were recessed to receive the feet of the piers.

316. The panels were composed of two leaves of clinker concrete slabs (about 2 ft. 8 in. long by 9 in. high by 3 in. thick) separated by a cavity 2 in. wide.

317. The piers were tongued and the slabs were grooved. The slabs were slid into position. Usually, mortar jointing was omitted, but in some cases both horizontal and vertical joints were grouted up in neat cement.

318. All the precast units were manufactured on the site; special plant was used for moving them and for erection. All concrete was of 1 : 6 mix; that used for the reinforced members having a stone aggregate and being cast "wet"; the clinker concrete blocks were made by the semi-dry process.

THE BOOT HOUSE



PRECAST REINFORCED CONCRETE PIERS WITH A CAVITY WALL OF 3″ CLINKER CONCRETE SLABS. INTERNAL AND EXTERNAL RENDERING. TIMBER JOISTS AND FLOORING

319. Openings in the walling were spanned with reinforced concrete lintels with splayed ends, which the piers were designed to receive. Piers and lintels were tied together with steel rods. No cavity gutters were provided over openings, at which the two members forming the piers were connected with solid concrete, to form the lintels. Except at openings, the cavity was continuous.

320. Externally the walls were roughcast. Internally, they were plastered.

321. PARTY WALLS. To first floor ceiling level, the party walls were of the same construction as the external walls. Above that, various infillings of brick and concrete slabs were used; chimney stacks and breasts were normally of brick, though in some schemes poured and precast units were used.

322. The remainder of the construction was conventional and varied in detail on the different sites.

THE WINGET PIER AND PANEL HOUSE

323. The Winget Pier and Panel system of house construction was developed by Winget Ltd. and Mr. F. Hill, and houses of this type were built as follows:

NO. OF HOUSES	SITUATION	DATE OF COMPLETION	OWNER
1262	Hull	1928	Hull Corporation
1000	Glasgow	1931	Glasgow Corporation
1250	Wakefield	1928	Wakefield Corporation
200	Norwich	—	Norwich Corporation

324. In all cases the schemes were built by contractors under licence from the patentees, who supervised the work. The Hull, Glasgow and Wakefield schemes have been inspected.

325. EXTERNAL WALLS. The external walls consisted of a reinforced concrete frame, with infilling of clinker concrete slabs, forming a cavity wall of a total thickness of 9 in.

326. The piers were of reinforced concrete, poured *in situ*. They were spaced at 3-ft. centres and occurred at the quoins, at the jambs of openings and at the junction of the external and party wall.

327. The beams were in the form of reinforced concrete wall plates at first floor level and roof level. They were poured *in situ*, and were 4 in. deep and 9 in. wide.

328. The piers at the quoins were cast in hollow precast clinker concrete blocks, 9 in. × 9 in. × 9 in., which formed permanent shuttering. The piers were formed and poured as the walling rose. At the junction of the external and party walls another special precast unit was used for permanent shuttering.

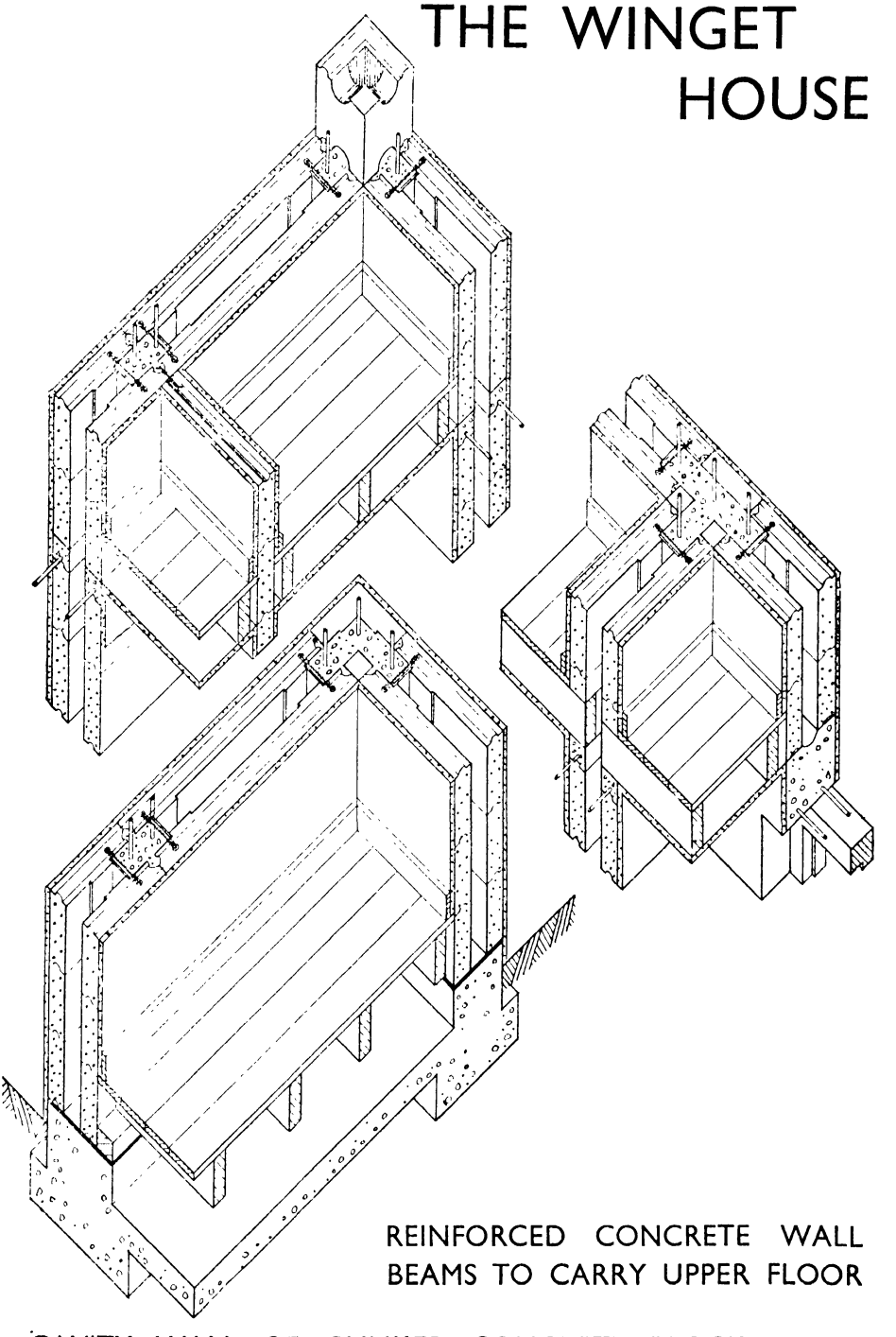
329. The intermediate piers were shuttered by the slabs, which were shaped for this purpose, while the cavity was closed by a strip of wood or building board. Slate strips were used to close the cavity and to form the base for the horizontal concrete beams; the sides were shuttered with wood strips.

330. The clinker concrete walling slabs were 3 ft. long, 9 in. high and 3 in. thick, the two leaves were separated by a cavity 3 in. wide. The intermediate piers occurred at every vertical joint between slabs.

331. PARTY WALLS. The party walls were of similar construction to the external walls. Chimney breasts and stacks were clinker concrete cast *in situ*, with fireclay linings to the flues.

332. The rest of the construction was conventional, and varied in detail on the different sites.

THE WINGET HOUSE



REINFORCED CONCRETE WALL
BEAMS TO CARRY UPPER FLOOR

CAVITY WALL OF CLINKER CONCRETE BLOCKS WITH REINFORCED CONCRETE PIERS POURED IN SITU. WALLS RENDERED EXTERNALLY AND PLASTERED INTERNALLY

THE UNDERDOWN HOUSE.

333. The following Underdown houses were built:

NO. OF HOUSES	SITUATION	DATE OF COMPLETION	OWNER
42	Cambridge	1926	Cambridge Corporation
92	Norwich	1926	Norwich Corporation
100	Eastbourne	1927	Eastbourne Corporation

The Cambridge and Norwich schemes have been inspected.

334. EXTERNAL WALLS. The 8-in. external cavity walls consisted of two leaves of concrete blocks 4 ft. long, 1 ft. deep, and 2 in. thick which were laid in cement mortar and wired together. The ends of the pair of blocks were so shaped as to provide permanent formwork for poured concrete piers (at 4-ft. centres) which tied the blocks together. Reinforced concrete piers cast *in situ* formed the main quoins, and these were tied together by continuous reinforced beams at first floor and roof levels. The quoins were cast in wooden angle profiles, the inner faces being supported by the walling blocks.

335. The composition of the concrete blocks was cement and fine stone and sand aggregate (about 1 : 6) and they were made semi-dry.

336. The walls were rendered externally either by hand or cement gun and plastered internally.

337. PARTY WALL. The party wall was of similar construction, but the chimney breasts and chimneys were of brickwork.

338. The remainder of the construction was conventional.

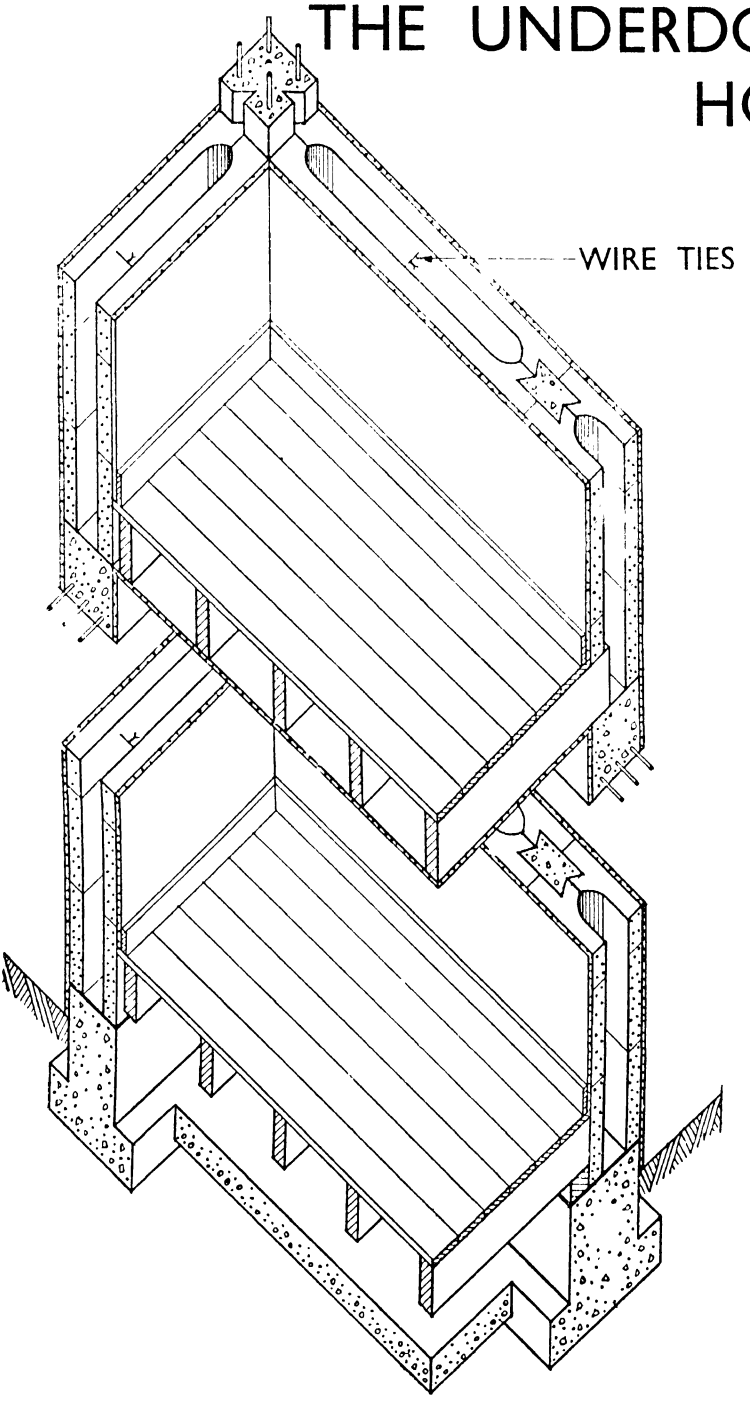
EFFICIENCY OF CONCRETE HOUSES WITH PRECAST CAVITY WALLS AND PIERS

339. STRENGTH AND STABILITY. The Duo-Slab houses are adequately strong and stable except that in the houses at Liverpool (which were built under licence) unsound clinker aggregate caused buckling of the walls, necessitating the insertion of steel ties. The major defects observed at Liverpool are in no way connected with this particular form of construction and might well develop in any concrete walls built with unsound aggregate.

340. No calculations on the strength and stability of the Boot, Winget and Underdown houses have been made by the Committee, but the fact that they have stood up for some 15–18 years without serious trouble indicates that the walls are sufficiently strong.

341. RESISTANCE TO MOISTURE PENETRATION. As no cavity gutters were provided, the resistance of the walls to moisture penetration depends on the efficiency of the applied rendering which, in turn, depends upon the stability of the clinker concrete backing. Cracks were observed on the rendering of all types and there is some evidence of moisture penetration except in the case of the Underdown houses. The rendering of the Winget and Underdown houses shows less cracking than that of the other types. This is in part due to the careful curing of the clinker slabs, and in part to the uniformity of the base provided by those constructions. (The piers of the Winget houses are faced with clinker aggregate.) It cannot be over-emphasised that unsound clinker and uncured slabs will inevitably give rise to movement and consequent cracking of rendering. Unsatisfactory design of constructional details of openings was also responsible for some moisture penetration.

THE UNDERDOWN HOUSE



CONCRETE BLOCKS FORMING CAVITY WALL, WITH REINFORCED CONCRETE PIERS. REINFORCED CONCRETE BEAMS CARRYING UPPER FLOOR

342. THERMAL INSULATION. The computed coefficient of heat transmission through the walls is 0·24 for Duo-Slab and Winget systems and 0·26 for the Boot system. Heat losses through the walls are, therefore, less than for an 11-in. cavity brick wall in all three types.

343. In the Underdown house the wall has a computed coefficient of 0·33, and heat losses are therefore greater than for an unventilated 11-in. cavity brick wall.

344. SOUND INSULATION BETWEEN HOUSES. While theoretical considerations suggest that the continuous cavity party wall construction of the Boot system should afford a considerable measure of discontinuity and so provide at least equal or greater resistance to the passage of sound than a 9-in. brick wall, the solid construction adopted in the roof space offsets this advantage and the resultant resistance is likely to be less than that provided by a 9-in. brick wall. The party walls adopted in the Duo-Slab, Winget and Underdown systems are also likely to be less efficient than a 9-in. brick wall.

345. FIRE HAZARD.

a. *Personal and Exposure Hazard.* The construction is comparable with normal brick and timber houses in respect of personal and exposure hazard and therefore satisfactory.

b. *Structural Hazard.* No data are available about the fire resistance of concrete party walls of these types. In general, it is felt that the construction is adequate if sound aggregate is used and if the walls are properly built and bonded into the chimney breasts. In some of the Winget houses the floor joists perforated the party wall. This is unsatisfactory.

346. VERMIN INFESTATION. No more harbourage is provided for bed-bugs than with normal brick walls, and disinfestation should not be more difficult than usual.

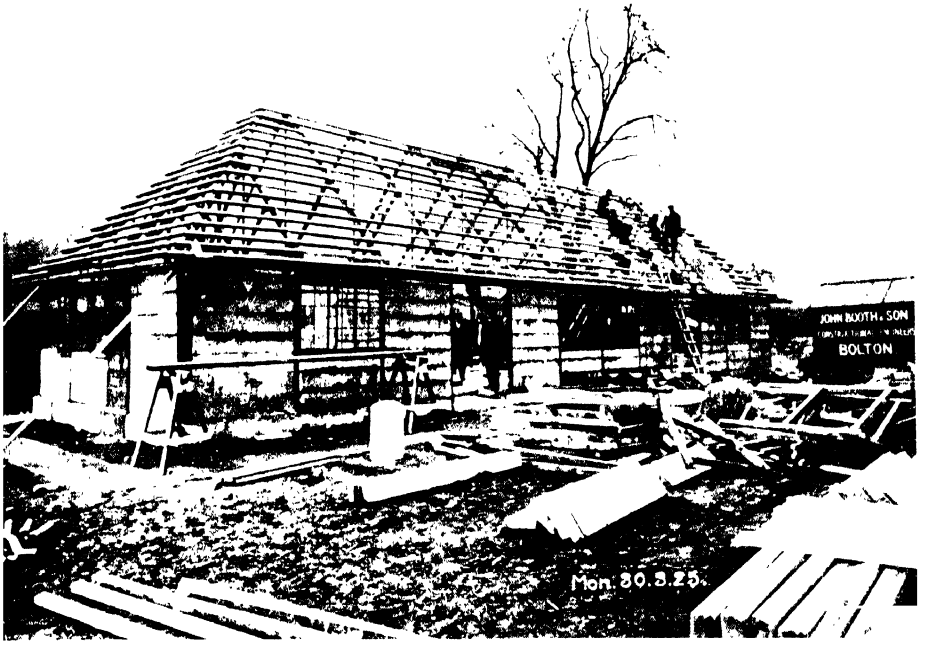
347. MAINTENANCE AND DURABILITY. In all types the durability depended upon the satisfactory curing of the slabs. Unsound clinker was the cause of high maintenance charges for some Duo-Slab houses.

348. GENERAL INFORMATION. There is no reliable evidence as to the initial cost or cost of maintenance of any of the pier and panel types. It does not appear that any substantial saving can be expected on the initial cost. Maintenance on one site has been heavy on account of the use of unsound clinker; on others it was stated the maintenance of the houses had not been greater than for brick houses.

349. Unskilled labour was used to erect the wall slabs; but some experience seems to be advisable, for it was noted that the Boot houses built on the Castelnau estate for the L.C.C., where skilled operatives were available, had been much more free from trouble than similar houses elsewhere. Opinions vary as to the speed of erection, but it seems likely that with good organisation an increase in speed can be expected on normal brick construction.

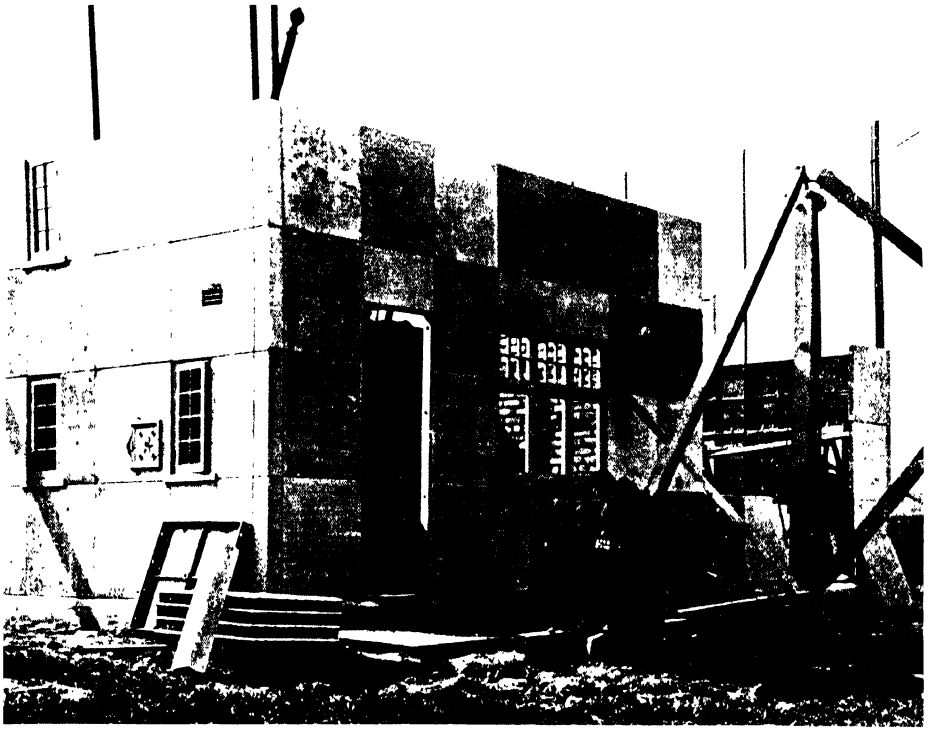
350. The houses were similar in appearance to normal rendered brick houses. The reactions of local authorities and tenants varied with the soundness of construction. Where extensive repairs have been necessary through the use of unsound clinker, the reactions were naturally unfavourable.

351. It is clear from the survey that satisfactory houses can be built with concrete frames and infilling in the form of cavity panels. The more successful systems were those in which a framework carried all the loads, and the panels were infilling in the true sense; the attempt to make the panels carry part of the loads and reduce the structure to a partly framed one has not proved so satisfactory in practice, especially when abnormal stresses were set up.



THE CRANE HOUSE IN CONSTRUCTION

See p. 79



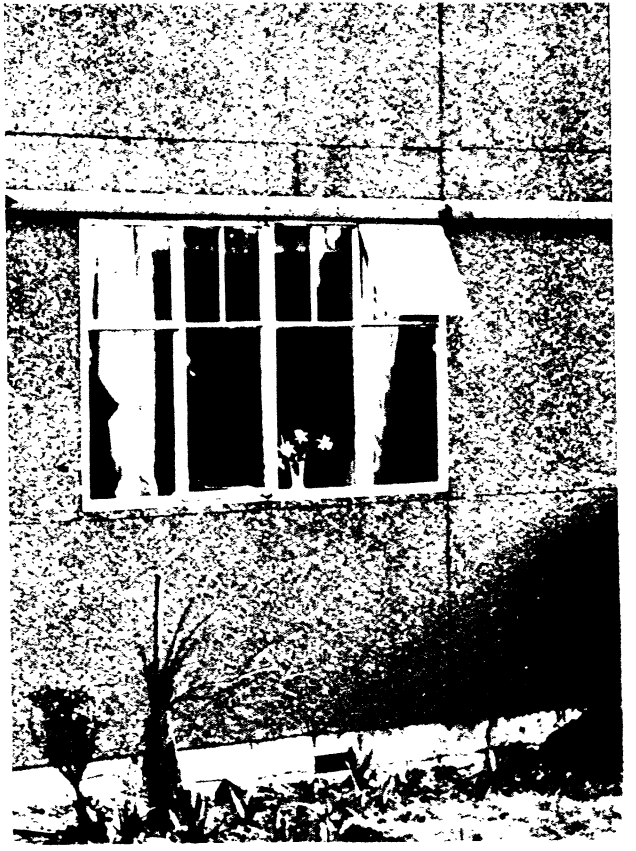
THE THORNCLIFFE HOUSE IN CONSTRUCTION

See p. 89



LIGHT STEEL FRAME

See pp. 73–80



JOINTING OF SHEETS IN THE WEIR HOUSE

See p. 80

352. The serious defects which occurred are not inherent to the system, but resulted from inferior design in detail or in the use of unsound material. Examples are the faulty design at openings in the walling, where the cavity is bridged by the lintel, etc., the use of immatured slabs; most serious, the use of unsound clinker as an aggregate, to which reference is made in Part III (paras. 739 and 740).

353. With good organisation, houses of this type should be built more cheaply and quickly than brick houses, and there is scope for the employment of labour inexperienced in the building industry.

CAVITY WALLS: CONCRETE BLOCK CONSTRUCTION

354. During the inter-war period, a number of houses were built with walls of solid concrete blocks laid in two skins separated by a cavity. Houses with this form of walling have been inspected in the following places:

NO. OF HOUSES	SITUATION	DATE OF COMPLETION	OWNER
407	Chepstow	1922	Private
132	Yeovil	1926	Yeovil Corporation
134	Liverpool	1923	Liverpool Corporation
500	Liverpool	1923	Liverpool Corporation
468	Fleetwood	1927	Fleetwood Corporation

355. EXTERNAL WALLS. The external walls consisted of two leaves of solid concrete blocks separated by a cavity. The blocks varied in size, but were commonly 1 ft. 6 in.×9 in. on face; and varied from 3 in.–4½ in. in thickness. Both stone and clinker aggregate were used; in some cases the same type of block was used for both leaves, and in some stone aggregate was used for the external leaf and clinker aggregate for the inner. Where clinker concrete was used externally it was finished with roughcast. The external walls of stone concrete were unrendered and left plain or tooled.

356. PARTY WALLS. The party walls were of concrete block walling, in solid or cavity construction and of stone or clinker aggregate. The overall thickness varied from 4½ in. (4½-in. clinker block, plastered both sides) to 9 in. (two 3-in. clinker slabs with 3-in. cavity, plastered both sides).

357. The rest of the construction was conventional, and varied on different sites.

358. STRENGTH AND STABILITY. All the forms of wall construction inspected appeared to be adequately strong and stable. (In the lightest form inspected the outer skin was of blocks 3 in. thick with a stone aggregate, and the inner skin was of clinker concrete blocks, also 3 in. thick).

359. RESISTANCE TO MOISTURE PENETRATION. On most sites there were cases of moisture having penetrated to the inner leaf of the wall; but it is considered that walls of concrete blocks should prevent such penetration if:

a. The blocks are well made and properly cured.

b. They are laid in a suitable mortar. In this connexion it is essential that a cement-lime or hydraulic-lime mortar be used—*i.e.* a mortar which is weaker than the block.

c. The accepted principles of cavity construction are followed, *e.g.* that the cavity be kept clean and the necessary gutters and flashings provided at points at which the cavity is bridged.

360. THERMAL INSULATION. The computed thermal transmission coefficients for these walls varied from 0·17 (2 leaves of clinker concrete, 4½ in. thick, 2-in. air space, rendering and plaster) to 0·32 (2 leaves of stone concrete 3½ in. thick, 3-in. air space and plaster), compared with 0·30 for an unventilated 11-in. brick cavity wall, plastered internally.

361. SOUND INSULATION. It seems likely that where the party wall consists of a cavity construction with 2 leaves of 3-in. or 3½-in. thick block the sound insulation will be about the same as that provided by a 9-in. solid brick wall. A solid block wall of 4½ in.–6 in. will be significantly inferior.

362. FIRE HAZARD.

a. *Personal and Exposure Hazard.* The construction is comparable with normal brick houses in respect of personal and exposure hazard and therefore satisfactory.

b. *Structural Hazard.* The thinner party walls (4½-in. breeze block plastered) would offer a resistance of two hours and would, therefore, comply with the proposed requirements. The thicker walls are comparable with 9-in. brickwork and therefore satisfactory.

363. VERMIN INFESTATION. The risk of vermin infestation is no greater than in brick houses. Disinfestation is no more difficult.

364. MAINTENANCE AND DURABILITY. Provided that the method of manufacture and the composition of the blocks are satisfactory there is no reason to doubt the durability of concrete block walls. The blocks should comply with *British Standard* 492.

365. GENERAL INFORMATION. Initial and maintenance costs appeared to be about the same as for cavity brickwork. There did not appear to be any considerable increase in speed of building, and skilled labour was necessary for the laying of the blocks, though stonemasons could be employed in place of bricklayers. The blocks, however, can be made by inexperienced workmen on the site by hand plant or power plant. The walls are apt to have a drab appearance unless suitably treated.

366. This form of walling provides a useful alternative to brickwork, in the event of a shortage of bricks.

CONCRETE WALLS

367. During the course of the survey certain general points in connexion with concrete walls emerged, which should be specially noted.

368. In many systems, in which clinker aggregate was used in concrete external walls, troubles arose from the use of unsound clinker. The troubles ranged from minor cracking to the threatened collapse of complete walls. In the early part of the inter-war period, the need for care in the selection of clinker for use as aggregate was not generally realised. Since then the subject has been studied, and a *British Standard* 834–1939 has been issued, which lays down standards of soundness and the tests for determining it. (Clause 194 and Appendices E, F and G.) The material may vary, so that all deliveries, unless guaranteed by the suppliers to conform to this British Standard, should be tested. The removal of the fine material from clinker aggregate reduces the risk of trouble from unsoundness, but this risk is eliminated by the use of alternative forms of lightweight aggregate. Such aggregates are described in Part III, para. 734 ff.

369. The commonest defect in concrete walls is cracking, especially as a result of the initial shrinkage. Care must be taken to see that precast concrete units are properly matured, and, generally, cast *in situ* concrete should be lightly reinforced to control such cracking. In this connexion it should be noted that clinker can be intrinsically corrosive to embedded steel, especially under damp conditions.

370. In some cases cracking in rendering has been due to the lack of uniformity in the backing or the failure to provide adequate key. Where concrete walls are to be rendered, uniform backing is desirable, otherwise cracking is likely to take place where a change of surface occurs.

371. In most cases the concrete walls investigated were not inferior to the 11-in. cavity brick wall in respect of thermal insulation. In those systems in which this was not the case, or where a higher standard is required, additional thermal insulation can be provided by lining the walls with some insulating material such as wood fibreboard or wood-wool, which can be in contact with the wall or, alternatively, separated from it, thus incorporating an air space to give additional thermal insulation.

FRAMED OR SOLID TIMBER HOUSES

372. Timber houses of various types have been built in different parts of Great Britain during the past twenty years. The details of construction and the types of timber used vary on the different schemes.

HOUSES BUILT BY THE SCOTTISH SPECIAL HOUSING ASSOCIATION

NO. OF HOUSES	SITUATION	DATE OF COMPLETION	OWNER
72	Polbeth and Kirknewton	1940	Scottish Special Housing Association
102	Coalburn	1940	
64	Douglas (N.B.)	1939	
92	Bathgate	1941	
2	Carfin Hall	1938	

Representative types have been inspected.

373. EXTERNAL WALLS. The external walls were of two types. In the one western red cedar was used and in the other Swedish fir. The former was untreated externally and the latter painted.

374. Usually the lower storey walls consisted of 2-in. tongued and grooved vertical boards, lined externally with wind-proof paper. The external finishing consisted of vertical $\frac{5}{8}$-in. boards and cover strips. Internally the framing was lined with plasterboard on $\frac{3}{4}$-in. wall battens.

375. The upper storey walls were of 4-in.×2-in. studding clad externally with $\frac{1}{2}$-in. diagonal boarding, wind-proof paper and horizontal weatherboarding, and internally with plasterboard on $\frac{3}{4}$-in battens.

376. On some of the sites the whole of the external walls were as described for the upper storey walls.

377. PARTY WALLS. The party walls were usually of 9-in. brickwork with brickwork chimney breasts, but in a few instances the party walls were only $4\frac{1}{2}$ in. thick.

378. PARTITIONS. The partitions were of two types—one consisting of 2-in. horizontal tongued and grooved boards lined on both sides with plasterboards on battens, and the other of timber-framed stud partitions lined with plasterboard nailed to the studding.

379. ROOFS. The roofs were of normal timber-framed construction; some were slated, others covered with cedar shingles. The roofs were unlined.

380. CEILINGS. All the ceilings were of plasterboard, on $\frac{5}{8}$-in. ceiling battens.

381. SITE CONCRETE. According to current Scottish practice, no site concrete was provided, the solum (area enclosed by the external walls) being covered with consolidated hardcore and ½-in. tar macadam.

382. The remainder of the construction was conventional.

HOUSES DEVELOPED BY SOLID CEDAR HOMES LTD., HULL

NO. OF HOUSES	SITUATION	DATE OF COMPLETION	OWNER
556	Dundee	1940	Dundee Corporation

383. EXTERNAL WALLS. The external walls consisted of prefabricated panels of 3-in. tongued and grooved cedar boards set vertically, lined externally with wind-proof paper. The external finishing consisted of vertical ¾-in. cedar boards and cover strips or cedar weatherboarding. Internally the walls were lined with ¼-in. plasterboard on ¾-in. battens.

384. PARTY WALLS. The party wall was constructed of precast concrete blocks 8 in. thick and the chimneys and flue gatherings were also built with precast concrete blocks.

385. SITE CONCRETE. The solum was covered with rough concrete 3 in. in thickness.

386. PARTITIONS. The partitions consisted of prefabricated panels of 2-in. (nominal) vertical tongued and grooved cedar boards lined on both sides with plasterboard on battens.

387. ROOFS. The roofs were of normal framed timber construction and covered with ⅝-in. roof boarding, felt, battens and plain tiles.

388. CEILINGS. The ceilings were of plasterboard, ⅜ in. in thickness.

389. The remainder of the construction was conventional.

HOUSES BUILT BY THE ABERDEEN CORPORATION

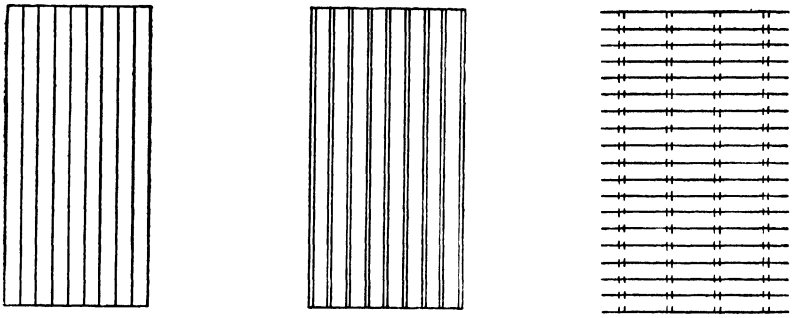
NO. OF HOUSES	SITUATION	DATE OF COMPLETION	OWNER
76	Aberdeen	1939	Aberdeen Corporation

390. EXTERNAL WALLS. Two forms of construction were used for the external walls. Those of the cottage type consisted of 5-in.×2-in. framing with studs spaced at 16-in. centres, lined externally with ⅝-in. deal boarding laid diagonally, wind-proof paper and ¾-in. untreated cedar weatherboarding. The internal lining was plasterboard nailed direct to the framing. In the upper parts of the gable walls the weatherboarding was replaced by cedar shingle hanging.

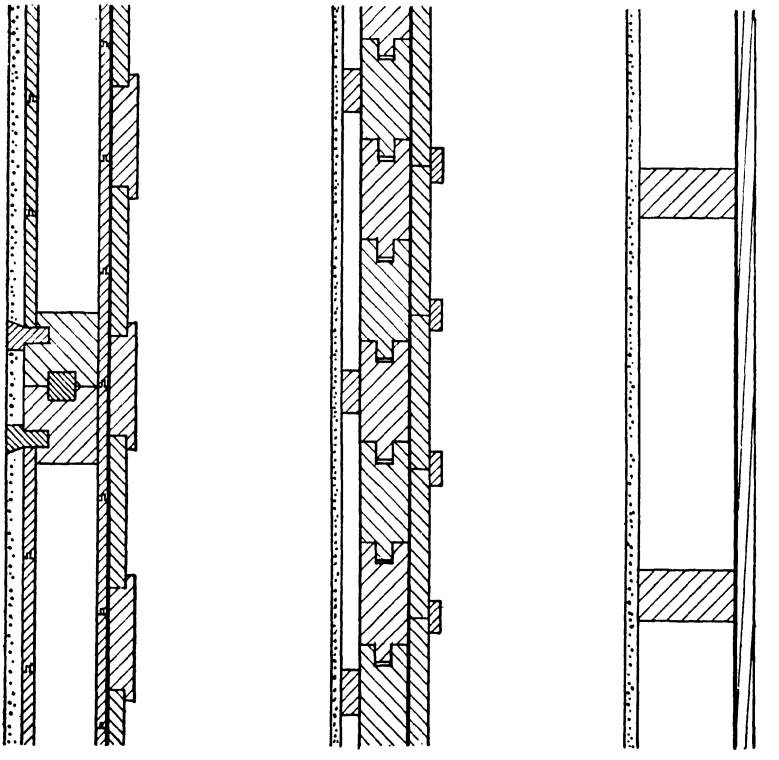
391. The external walls of the flatted type consisted of 3-in. tongued and grooved deal boards set vertically, lined externally with wind-proof paper and ¾-in. red cedar weatherboarding. Internally the walls were lined with plasterboard on ¾-in. battens.

392. PARTY WALLS. The party walls were built in brickwork 6 in. thick, a special brick of Scottish type 6 in. thick being used. The chimneys were built in brickwork.

TIMBER-FRAMED WALLS



SMALL SCALE ELEVATIONS



LARGE SCALE PLANS

NORWEGIAN

PREFABRICATED PANEL: 3″×3″ TONGUED STUDS; COVERED EXTERNALLY WITH REBATED PANELS AND BUILDING PAPER ON ½″ BOARDING; INTERNALLY WITH ¼″ FIBREBOARD ON ½″ BOARDING

SWEDISH

PREFABRICATED PANEL: 3″ T. & G. PLANKS LAID HORIZONTALLY; COVERED EXTERNALLY WITH ½″ BOARDS, COVER STRIPS AND BUILDING PAPER; INTERNALLY WITH ½″ PLASTERBOARD ON BATTENS

ENGLISH

CONSTRUCTED ON SITE: 4″×2″ STUDS; COVERED EXTERNALLY WITH CREOSOTED WEATHERBOARDING AND BITUMEN FELT; INTERNALLY WITH ½″ FIBREBOARD

393. SITE CONCRETE. In accordance with current Scottish practice, the solum was covered with consolidated hardcore and ½-in. asphalt.

394. PARTITIONS. The partitions were of framed timber construction lined with ⅜-in. plasterboard.

395. ROOFS. The roofs were timber-framed with ⅝-in. roof boarding, felt and tile covering without battens.

396. CEILINGS. The ceilings were of plasterboard.

397. The remainder of the construction was conventional.

HOUSES PREFABRICATED IN NORWAY AND BUILT BY THE NEWCASTLE CORPORATION

NO. OF HOUSES	SITUATION	DATE OF COMPLETION	OWNER
100	Newcastle-on-Tyne	September 1927	Newcastle-on-Tyne Corporation

398. EXTERNAL WALLS. The walls consisted of prefabricated panels 4 ft. wide and one storey in height constructed of 3-in.×3-in. frames with 2½-in.×2½-in. horizontal members, lined externally with ½-in. vertical tongued and grooved boarding and internally with similar boarding ⅜ in. thick. After erection of the panels vertical boarding with rebated joints consisting of alternate ¾-in. and 1-in. boards was fixed externally over wind-proof paper. The external face was painted. A proprietary Norwegian wall board was used as an internal lining: it was fixed by wooden wedge-shaped strips. The board was claimed by the manufacturers to be fireproof. The main quoins of the blocks of houses were strengthened by means of 4-in.×4-in. posts.

399. PARTY WALLS. The party walls and chimneys were of normal brick construction, the walls being 9 in. thick.

400. GROUND FLOOR. The ground floor was of prefabricated construction consisting of 4-in.×2-in. joists, ⅝-in. rough boarding and 1-in. tongued and grooved flooring.

401. DOORS AND WINDOWS. The doors and windows formed part of the prefabricated wall panels.

402. PARTITIONS. The partitions were of prefabricated panels formed of 4-in.×2-in. framing and studs, 4 ft. wide and the full room height, lined with the proprietary wall board.

403. ROOFS. The roofs were timber-framed with an unlined slate covering.

404. CEILINGS. The ceilings were of prefabricated panel construction consisting of 4-in.×2-in. joists, ½-in. rough boarding, and covered with the proprietary wall board.

405. The remainder of the construction was conventional.

HOUSES BUILT BY THE LONDON COUNTY COUNCIL

NO. OF HOUSES	SITUATION	DATE OF COMPLETION	OWNER
464	Watling	1926	London County Council
205	Becontree	1926	

The Watling Scheme has been inspected.

TIMBER HOUSES

406. EXTERNAL WALLS. The external walls consisted of 4-in.×2-in. framed studding covered externally with creosoted weatherboarding $\frac{3}{4}$ in. thick on thin bitumen felt and internally with $\frac{1}{2}$-in. wood fibreboard.

407. PARTY WALLS. The party walls were built of 9-in. brick with brick chimney breasts.

408. PARTITIONS. The partitions were of framed studding lined with wood fibreboard.

409. ROOFS. The roofs were of framed timber construction covered with single lap tiles without a lining.

410. CEILINGS. The ceilings were of $\frac{1}{2}$-in. wood fibreboard.

411. The remainder of the construction was conventional.

EFFICIENCY OF TIMBER HOUSES

412. STRENGTH AND STABILITY. All types gave adequate strength and stability.

413. RESISTANCE TO MOISTURE PENETRATION. Generally no penetration occurred, but some trouble was experienced on one site with penetration between door frames and the weatherboarding, through vertical joints and through windows. These troubles were all due to unsatisfactory design in detail and can be readily eliminated in future houses.

414. In the case of the Newcastle houses, difficulty was experienced at first by the continued dampness of the wall and ceiling board (Kivronmasse). It was found that this had been "fireproofed" with a hygroscopic salt which caused dampness. Painting the boards overcame the trouble.

415. THERMAL INSULATION. The computed thermal transmission co-efficients of the walls varied from 0·17 to 0·30, so that in most types the insulation provided is superior to normal construction.

416. SOUND INSULATION. No complaints have been made regarding the sound insulation provided by the party walls, though the walls at Aberdeen (6-in. brick) and in some other Scottish houses (4½-in. brick) fall below the standard of the normal 9-in. brick wall.

417. FIRE HAZARD. On one site only has a serious fire occurred and in this case a house was completely destroyed in about two hours. The brick party wall and the efforts of the neighbours prevented the spread of the fire to the adjoining houses.

a. *Personal Hazard.* It is not considered that any special personal hazard arises in timber houses unless internal linings of inflammable materials are used, *e.g.* untreated fibreboard. The Kivronmasse used in the houses at Newcastle is claimed by the makers to be fireproofed.

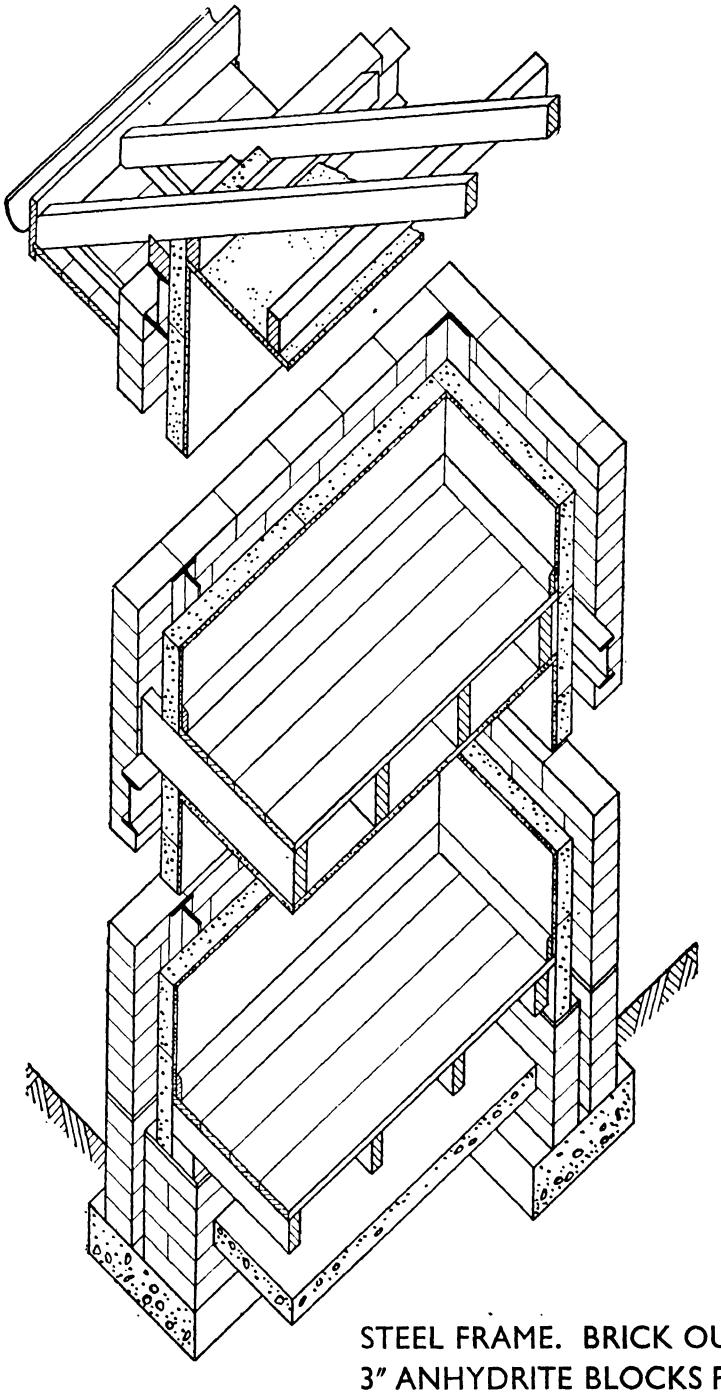
b. *Structural Hazard.* In all the houses covered by this report the party walls are considered satisfactory. In the absence of prompt fire fighting the remainder of the structure will be totally consumed.

c. *Exposure Hazard.* Existing requirements relating to the spacing of buildings with combustible walls or roofs are given in Part I of this report.

418. Judging by these standards, the spacing of some of the houses inspected was inadequate.

419. MAINTENANCE AND DURABILITY. The durability of the houses depends largely upon the resistance of the wood to fungal attack. Western red cedar is immune from such attack, but the deal houses need careful painting to prevent decay. At present the houses of both types are in good condition. The deal houses have been repainted since erection.

THE DENIS POULTON HOUSE



STEEL FRAME. BRICK OUTER SKIN.
3" ANHYDRITE BLOCKS PLASTERED
AS INNER SKIN. ROOF NORMAL

TIMBER HOUSES

420. VERMIN INFESTATION. There has been little experience of vermin infestation on the sites inspected, but it is considered essential that precautions should be taken with both the solid and framed walls to prevent access of vermin to the space behind the wall linings. Disinfestation of some framed houses has proved difficult.

421. GENERAL INFORMATION. On all sites the tenants stated that they found the houses comfortable and equal in all respects to normal brick houses. No major defects have developed in any of the houses.

422. The construction for the most part is dry and the houses can be inhabited immediately on completion.

423. It would appear that most of the timber houses were built at a slightly higher cost than brick houses.

424. The maintenance costs have generally been the same as those for brick houses.

425. Most of the houses were built at about the same speed as brick houses, but those prefabricated in Norway showed a definite saving in site labour. Bricklayers' labour was necessarily less for the timber houses than for brick houses, but there is no overall saving in craftsmen's labour.

426. The cedar houses especially have a good appearance. The appearance of the deal houses depends largely upon the condition of the external paintwork.

STEEL-FRAMED HOUSES

THE DENNIS-WILD HOUSE

427. The Dennis-Wild system of house construction was developed by James Wild and Co. (Housing), Ltd., and houses of this type were built as follows:

NO. OF HOUSES	SITUATION	DATE OF COMPLETION	OWNER
About 9000	On various sites in England, *e.g.* Hull, Norwich, Manchester, etc.	About 1928	Various local authorities and private owners

Schemes at Manchester, Hull, York, and Norwich have been inspected.

428. STEEL FRAME. The frame was of standard rolled-steel members. The stanchions and beams were of heavier section than was used in some other steel-framed houses and correspondingly widely spaced. In some schemes the stanchions were encased in concrete. The Wild Patent Cradle Roof Truss was used to support the timber secondary members of the roof.

429. The rest of the construction was conventional.

THE DENIS POULTON HOUSE

430. The Denis Poulton houses were designed by Denis Poulton, architect, and houses of this type were built as follows:

NO. OF HOUSES	SITUATION	DATE OF COMPLETION	OWNER
12	Haversham	1937	Private
16	Wigston	1936	Private

Both schemes have been inspected.

431. STEEL FRAME. The frame was of standard rolled-steel members, of comparatively heavy section, spaced at 10-ft.–12-ft. centres. The stanchions in the external walls were 4-in.×4-in.×$\frac{5}{16}$-in. angles or 4-in.×3-in.×$\frac{3}{8}$-in. tees, and the beams varied between 5-in.×2½-in.×9-lb. and 7-in.×3½-in.×15-lb. R.S.J.s. The steel was protected with a thick coat of tar, applied after erection. All connexions were made by bolting.

432. At Wigston all wall, partition, and ceiling linings were of wall boards or blocks which could be decorated immediately. The steel frame was made with precision so that floor and roof units and other members could be cut to size or manufactured off the site and fixed with a minimum of site labour.

433. The rest of the construction was conventional.

THE DORLONCO HOUSE

434. The Dorlonco system of construction was promoted by Messrs. Dorman Long and Co., Ltd., and houses of this type were built as follows:

NO. OF HOUSES	SITUATION	DATE OF COMPLETION	OWNER
About 10,000	In various parts of the country, including Doncaster, Welwyn Garden City, Liverpool, and Gloucester	1920–28	Various local authorities
258	Aylesham, Snowdown, and Woolage, Kent	1927	Pearson, Dorman Long and Co., Ltd.

The schemes at the places mentioned in the table have been inspected.

435. The promoters were responsible only for the general design of the houses and the manufacture and erection of the steel frames. The remainder of the work was carried out by building contractors or by direct labour.

436. FRAME. The framework, which carried the first floor and roof and to which in the majority of the houses was fixed the external cladding, consisted of light rolled-steel members, mostly of angle or channel section, connected by bolts. The stanchions in the external walls were 4-in.×2-in.×¼-in. angles, at 4-ft. centres; the floor beams (to first floor) were 5-in.×2½-in. or 4-in.×2-in. channels. The framework was protected against corrosion by painting with bituminous paint.

437. EXTERNAL CLADDING. In the majority of the houses—*i.e.* the earlier type—the outer leaf of the external cavity wall consisted of cement rendering on ribbed metal lathing fixed to steel rods. The lathing and rods were tied to the angle stanchions by soft wire. The total thickness of the outer leaf was 1½ in.

438. The inner leaf of the external wall was of 2-in. clinker slabs, plastered. The cavity was 4 in. wide and the stanchions were within it.

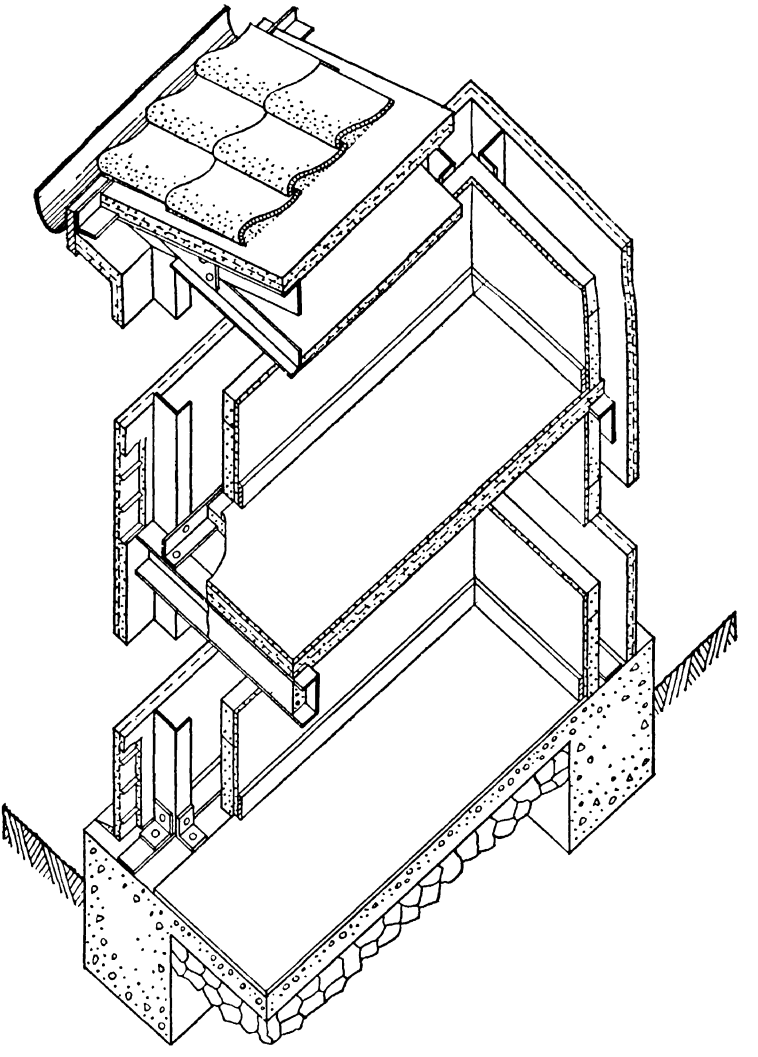
439. In the houses built for Pearson, Dorman Long and Co., Ltd., three types of solid external walling were used, namely:

a. An inner lining of clinker slabs 2 in. in thickness, with an outer lining of concrete reinforced with steel mesh and applied by a cement gun.

b. A similar inner lining, tar-sprayed on the outer face, with a cast *in situ* external lining of concrete 3 in. thick reinforced with steel mesh.

c. Similar construction to (*b*), but with a 1-in. layer of compressed cork between the outer and inner linings, the cork being attached to the clinker slabs during manufacture.

THE DORLONCO HOUSE



STEEL FRAME WITH EXTERNAL METAL LATHING RENDERED ON BOTH SIDES. INNER SKIN OF BREEZE SLAB PLASTERED. CONCRETE ROOF ON STEEL TRUSS

440. FIRST FLOOR. The first floor was of cement concrete, 1½ in. thick, laid on ribbed metal lathing, and finished with a screed of coloured cement and sand, ½ in. thick. The lathing was carried on beams of channel section, which projected below the ceiling and were filled with concrete, showing a rectangular profile. The ground floor ceiling was finished with a ⅜-in. cement rendering on the soffit of the metal lathing.

441. ROOF. The roof framing was of light steel members finished with tiles or slates on boarding nailed direct, or with pantiles on 2 in. of clinker concrete on ribbed metal lathing.

442. The ceiling to the first floor was of 1½-in. concrete on ribbed metal lathing cement rendered on the under side.

443. PARTY WALL. The party wall was of cavity construction, consisting of 2 leaves of 2-in. clinker concrete blocks, separated by a 4½-in. cavity. At first-floor level angle beams of the framework were built into each leaf.

444. The rest of the construction was conventional.

EFFICIENCY OF DENNIS-WILD, DORLONCO, AND DENIS POULTON HOUSES (STEEL-FRAMED)

445. STRENGTH AND STABILITY. Experience has shown the steel frame and walls of the Dennis-Wild and Denis Poulton houses to be amply strong. Full-scale tests were made on the frame of the Denis Poulton house, with satisfactory results.

446. The Dorlonco steel frame also has proved amply strong and stable as have the walls and floors, apart from certain troubles referred to later.

447. RESISTANCE TO MOISTURE PENETRATION. The resistance of the walls to moisture penetration was not affected by the introduction of the steel frame to carry the loads of roof and floor. There was evidence of moisture penetration through the walls of Dennis-Wild houses built at York, where the outside walling above the level of the first-floor window-sill was of concrete blocks. Rendering was resorted to in a number of cases in an endeavour to cure the trouble. Where the change from brickwork to concrete blocks occurred, the cavity was bridged by a solid concrete string course, without cavity flashing. Moisture penetrated at this point also. There were no complaints of dampness in the Denis Poulton houses.

448. In some Dorlonco houses moisture penetration was experienced after corrosion of the metal lathing occurred. Otherwise the walls were satisfactory in this respect.

449. THERMAL INSULATION. The thermal insulation depends on the form of construction of the outside walls. In the Dennis-Wild and Denis Poulton houses it was about the same as for normal 11-in. brick cavity walls.

450. The coefficient of thermal transmission for the walls of the Dorlonco houses in which cork was used is 0·24 compared with 0·30 for an 11-in. unventilated cavity brick wall, thus being superior to the latter in this respect. The other forms of construction were slightly inferior to the standard of the 11-in. wall.

451. SOUND INSULATION. In the Dennis-Wild and Denis Poulton houses the party wall of 9-in. brickwork, lined both sides with plasterboard on battens, permits less sound transmission than a similar wall plastered on the solid; however, there is a risk that impact noises may be transmitted along the steel frame, which is continuous through the wall.

452. The continuous steel frame and light construction of the party walls of the Dorlonco houses tended to make the latter more susceptible to the transmission of impact and airborne sounds. However, slight modifications could be made in future houses to improve resistance to airborne sounds. Where uncarpeted the solid concrete floors were less effective against impact sounds than normal timber floors, but airborne sounds were transmitted to a less degree.

453. FIRE HAZARD. *Personal, Structural, and Exposure Hazard.* Apart from those cases in which the walls were lined with wood fibreboard or a light construction was adopted for the party walls, the construction was satisfactory in respect of fire hazard. In the latter case, although 4 in. of incombustible material should normally be adequately resistant to fire for domestic construction, the incorporation of structural steelwork in the walls might increase the element of hazard, but no test data on walls of this type are available at present. The solid floors and ceilings of the Dorlonco houses would be expected to reduce the personal and structural hazards from those associated with normal timber floors.

454. VERMIN INFESTATION. The problems of vermin infestation and disinfestation are not more serious with this than with normal construction, and indeed the solid floors and ceilings of the Dorlonco houses are less likely to provide harbourage than normal timber and plaster constructions.

455. MAINTENANCE AND DURABILITY. Maintenance and durability depends largely upon the resistance of the steel frame to corrosion. In some cases the steelwork was encased in concrete, and in others a thick coat of tar or bitumen paint was applied to the steelwork after erection. As far as is known all three methods proved satisfactory.

456. The durability of all the walls of the Dorlonco houses was satisfactory with the exception of houses, on certain sites, which were clad with rendering on metal lathing. In some of these houses corrosion of the lathing and ties occurred, necessitating a renewal of the outer leaves of the walls in various forms of construction. This failure of the cladding cannot, however, be attributed to any fault of the system of construction, for if proper precautions are taken the cladding should be durable. It is mentioned here solely as a guide for future work. Where this construction is used it is essential for the lathing to be completely embedded in dense cement mortar by back rendering or consolidation, for the tyings to be of robust construction and protected against corrosion and for the composition of the rendering to be suitable for this class of work. On some sites the rendered lathing has given no trouble over periods of twenty years, which appears to indicate that this form of construction can be satisfactory. The promoters of the system were not responsible for the composition or application of the rendering.

457. Shrinkage cracking in the outer leaf of the walls of the later type houses was not extensive nor of serious consequence: most occurred over strips of timber used as construction joints and none permitted moisture penetration.

458. GENERAL INFORMATION. No reliable data are available of comparable figures for initial cost of Dennis-Wild houses and similar brick houses built at the same time. From available figures it appears that in one locality the cost per cu. ft. was higher than that for brick houses having approximately the same accommodation but of greater cubic content.

459. Denis Poulton houses were designed for two firms of builders who proposed to build a considerable number of them for sale. The selling price was £595. The houses were larger (about 1100 sup. ft.) than the normal State-aided houses, and fittings and finishings of a higher standard were provided. This should be

taken into account in comparing the costs of the two types. After 28 houses had been finished the price of steel rose, and the method of construction became uneconomic and it was abandoned in favour of load-bearing brick cavity walls. No figures of initial cost are now available, but it is claimed that the houses were built at such a cost that the selling price showed a fair margin of profit.

460. It did not appear that the full possibilities of steel-frame construction were exploited in these two systems, as the walling materials were of a load-bearing character, although they did not, in fact, carry loads. The promoters claimed that the use of a steel frame would lead to greater speed in building, as the early completion of the roof made a large proportion of the work independent of weather conditions, and that the savings on such items as setting out and scaffolding, for which the frame can be used, at least offset the cost of the steel.

461. It is understood that the majority of the Dorlonco houses were less costly than brick houses built at the same time and were more rapidly constructed. The Dorlonco steel frame is of economical design, and owing to the close spacing of the stanchions can be used to support any type of external or internal lining.

462. In the earlier type the steel frame carried all floor and roof loads and supported the external cladding in addition to the inner leaf from the first floor upwards. It would appear that, provided a satisfactory external cladding is used, the system provides a useful alternative to normal brick construction.

463. In respect of comfort and appearance, there was no appreciable difference between these houses and those of normal construction.

THE NISSEN-PETREN HOUSE

464. The Nissen-Petren system of house construction was developed by Nissen-Petren, Ltd., and houses of this type were built as follows:

NO. OF HOUSES	SITUATION	DATE OF COMPLETION	OWNER
6	Barwick	1926	Yeovil Rural District Council
6	West Camel	1926	
8	South Petherton	1926	
A small number in other cities and towns in England and Scotland		1926	Edinburgh Corporation, Yeovil Corporation, and other local authorities

The Barwick houses have been inspected.

465. In the Nissen-Petren house, the roof was supported by four T steel ribs curved from ground-floor level to a semicircle with radius equal to half the frontage of a pair of houses, connected with steel angle iron purlins. The front and back and the side external walls up to first-floor level were of cavity construction—the outer leaf of 3-in. stone aggregate concrete blocks roughcast, the inner 3-in. clinker aggregate blocks plastered. The roof of protected metal sheets was curved to fit the ribs. Party walls were of cavity construction with two 3-in. clinker concrete slab leaves. The remainder of the construction was conventional.

466. A small number of these houses were built. They proved fairly efficient, but the method of construction limited the scope for design, and the houses are not likely to make any general appeal.

THE CRANE HOUSE

467. The Crane system of house construction was developed by Alderman Crane of Nottingham, and houses of this type were built as follows:

NO. OF HOUSES	SITUATION	DATE OF COMPLETION	OWNER
400	Nottingham	1926	Nottingham Corporation

468. FRAME. The frame consisted of steel T section stanchions 3 in.× 3 in. at about 6-ft. centres, the bases of which were steel shoe plates embedded in the concrete raft. Steel roof trusses at similar centres consisted of 2½-in.× 2½-in.× $\frac{5}{16}$-in. T section rafters, 3-in.× 3-in.× $\frac{5}{16}$-in. T section tie beams, 2½-in.× 2½-in.× $\frac{5}{16}$-in. struts and hangars. 3-in.× 3-in. steel ceiling bearers at 3-ft. centres were provided.

469. ROOF. The roofs were at 45° pitch and were constructed of the steel trusses; 2½-in.× 1½-in. purlins (used as tiling battens) fixed to steel cleats at 11¾-in. centres; asbestos cement pantiles, ridges and hip tiles. A felt roof lining was provided.

470. EXTERNAL WALLS. The external walls were built of clinker concrete blocks about 6 ft. long, 1 ft. high and 5 in. thick rebated to fit the steel stanchions. The blocks were rough faced externally to receive roughcast and were faced internally during manufacture with smooth surfaces to receive wallpaper. The horizontal joints of the blocks were tongued and grooved, and the blocks were set in cement mortar with flush plaster pointing internally.

471. PARTY WALL. The party wall was of cavity construction consisting of two leaves of 3-in. clinker slab walling. The slabs were finished externally with smooth surface to receive wallpaper. The overall thickness was 7½ in.

472. CHIMNEYS. The only chimney serving a combination range was of cast-iron pipes passing through the ceiling of the kitchen and the roof at the ridge. A clay chimney pot was provided through which the cast-iron pipe passed.

473. FLOORS. The floors of the living rooms, bedrooms and hall were covered with magnesium oxychloride flooring and the remainder with cement concrete paving.

474. PARTITIONS. The partitions were of 3-in. thick plaster slabs reinforced with reeds and finished smooth to receive wallpaper.

475. CEILINGS. The ceilings were of $\frac{5}{16}$-in. asbestos cement sheets in 3-ft.× 3-ft. panels resting on flanges of the steel T members and fastened by metal pegs.

476. The rest of the construction was conventional.

477. STRENGTH AND STABILITY. The strength and stability of the houses which were of one storey only was adequate.

478. RESISTANCE TO MOISTURE PENETRATION. No trouble was experienced with penetration of moisture through the walls or roofs. A generous eaves overhang was provided; the walls were only some 9 ft. in height and an efficient roughcast rendering was provided.

479. THERMAL INSULATION. The computed thermal transmission of the walls is 0·32, which is slightly inferior to that for 11-in. unventilated brick cavity walls. The asbestos cement ceilings are less efficient than the normal lath and plaster ceilings and the heat losses through the ceilings and roof are, therefore, slightly higher than with normal construction.

480. SOUND INSULATION. The party wall should provide slightly greater resistance to the transmission of air-borne sound than a 9-in. solid wall of brickwork. The partitions were of slab construction and their resistance to air-borne sound was adequate.

481. FIRE HAZARD.

Personal, Structural and Exposure Hazards. In all respects the construction was satisfactory.

482. VERMIN INFESTATION. The houses did not differ from normal brick houses with sheet material ceilings in respect of vermin infestation or disinfestation.

483. MAINTENANCE AND DURABILITY. The durability of the houses appears to be adequate. No signs of corrosion of the steelwork were apparent and no trouble from unsoundness was experienced with the clinker aggregate used in the walling blocks. The asbestos cement tiles were in good condition.

484. GENERAL INFORMATION. The houses have proved efficient and satisfactory to the local authorities, tenants and to some 250 owner-occupiers.

485. There is reason to think that the houses were constructed considerably more rapidly than brick houses, though no definite data were available.

486. The cost of the houses, £476 (750 sq. ft. floor area), was comparable with the cost of brick houses with similar accommodation, but a high proportion of labour inexperienced in building work was employed in construction. There was no internal plastering and work involving the employment of skilled craftsmen was generally reduced to a minimum.

487. In a few cases where chimney fires occurred the cast-iron flue pipes used as chimneys were not completely satisfactory. Some cracked and repairs were necessary to the roof fillets around the pipes and chimney pots. It is considered by the local authorities that fireclay pipes would be more durable and satisfactory.

488. Crane houses were designed and built in 1925 with the object of reducing as far as possible the employment of building industry craftsmen in the construction. Success was achieved in this object and the houses have proved efficient and satisfactory to owners and tenants. The system provides a good alternative to normal brick construction.

METAL-CLAD HOUSES

THE WEIR HOUSE

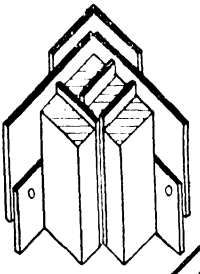
489. The Weir system of house construction was developed by Cardonald Housing Corporation, Ltd., and houses of this type were built as follows:

NO. OF HOUSES	SITUATION	DATE OF COMPLETION	OWNER
1552	On a number of sites chiefly in South Scotland	1927	Second Scottish National Housing Co. (Housing Trust), Ltd.
A smaller number distributed over a number of sites in England		1927	Various local authorities

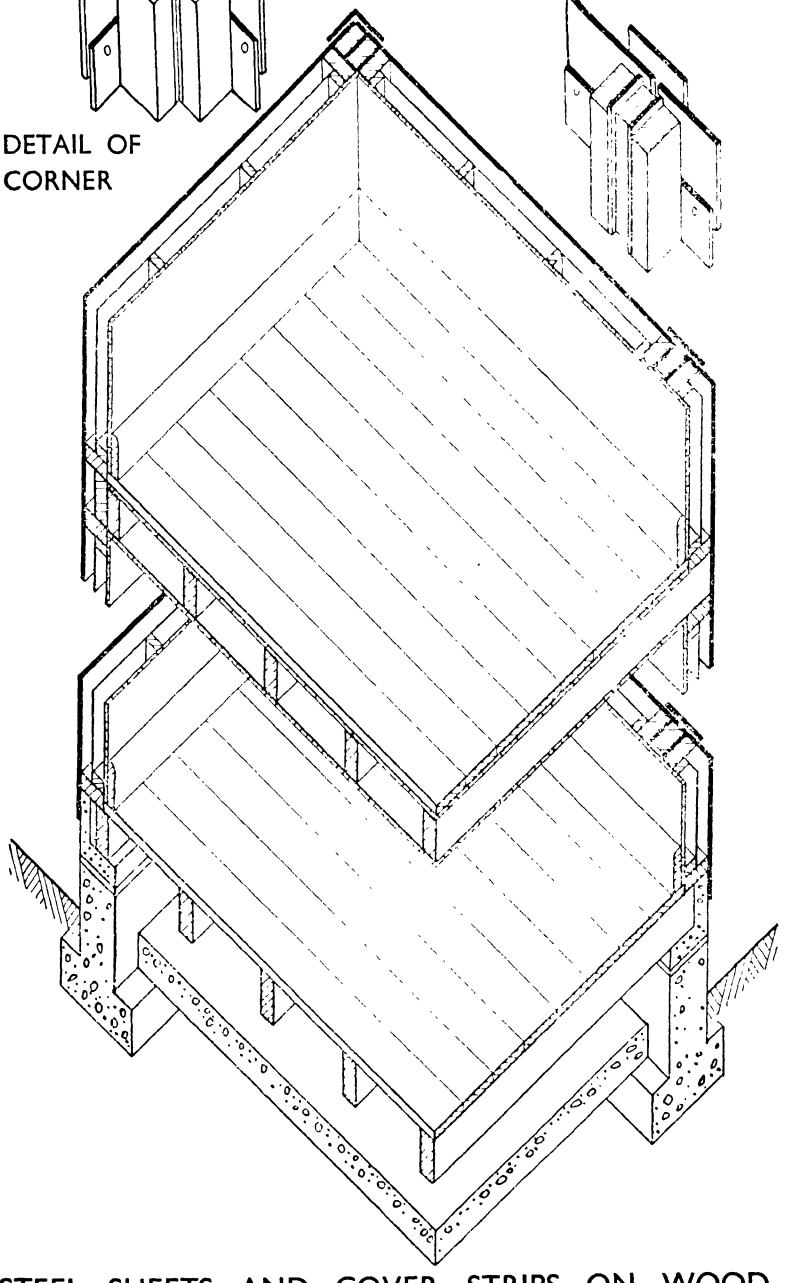
A number of schemes were inspected.

490. EXTERNAL WALLS. The external walls consisted of a wooden framing, clad externally with steel sheets and internally with pulpboard. The steel sheets were of ⅛-in. plate (ground floor) and 12 gauge sheets (first floor), protected against corrosion on the inside with black stoved enamel. Plain lapped joints were used

THE WEIR HOUSE



DETAIL OF CORNER



STEEL SHEETS AND COVER STRIPS ON WOOD FRAME. INNER SKIN OF FIBREBOARD WITH FELT MEMBRANE FOR INSULATION AND TWO AIRSPACES

horizontally between the sheets and the latter were fixed to the framing by drive screws. Flat steel cover strips 6 in. wide were used to cover the vertical joints.

491. The internal lining was of $\frac{3}{8}$-in. laminated pulp-board.

492. The cavity, 4 in. wide, was sealed, and divided into two compartments by a vertical sheet of bituminous building paper.

493. The external finish was paint and later, in many cases, paint harling. Internally the laminated pulp-board had wood cover strips and was distempered. A plywood dado was provided in the living room and hall.

494. PARTY WALLS. The party walls were constructed of wood studding, faced on both sides with wood-wool slabs which at a later date were replaced by a single thickness of clinker concrete block walling, 2 in. thick. Chimney breasts and stacks were of precast concrete blocks.

495. The rest of the construction was conventional, and varied in detail on different sites.

THE ATHOLL HOUSE

496. The Atholl system of house construction was developed by Atholl Steel Houses, Ltd., and houses of this type were built as follows:

NO. OF HOUSES	SITUATION	DATE OF COMPLETION	OWNER
500	On a number of sites chiefly in South Scotland	1927	Second Scottish National Housing Co. (Housing Trust), Ltd.
252	Watling Estate, Burnt Oak	1927	London County Council
A smaller number distributed over a number of sites in England		1927	Various local authorities

A number of schemes in Scotland and England have been inspected.

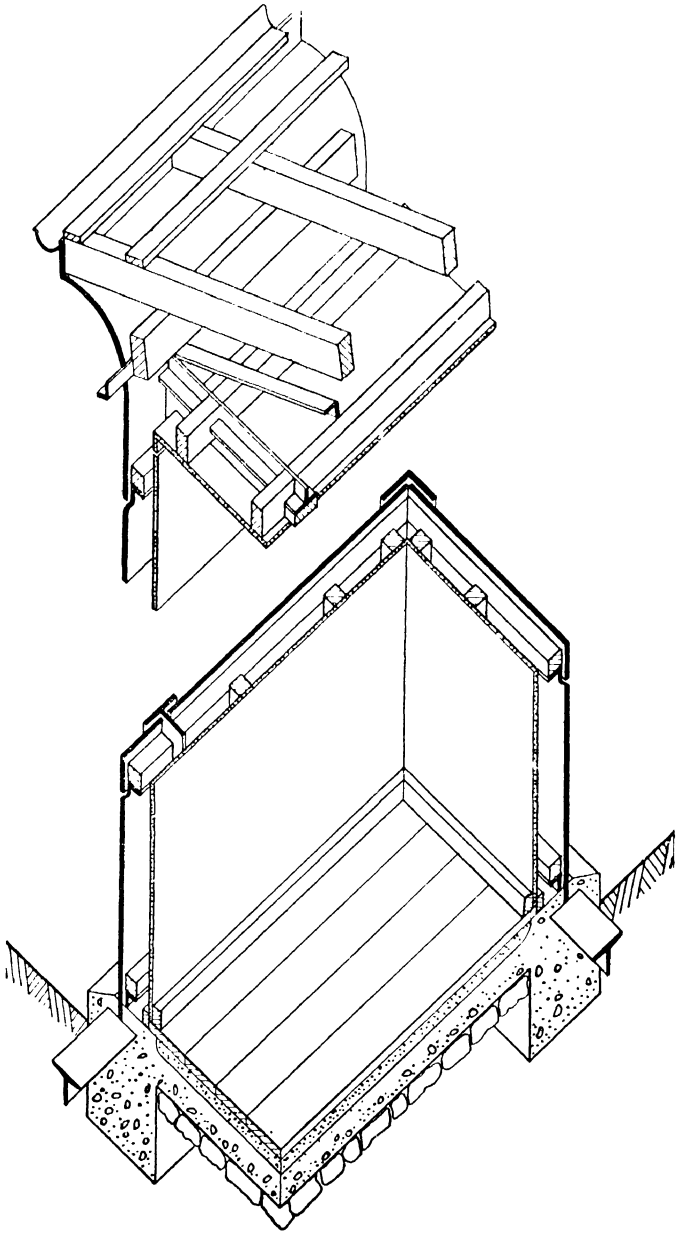
497. The Atholl houses built in Scotland and London differed to some extent: where differences occurred, these are noted below.

498. EXTERNAL WALLS. The external walls consisted of a steel framing, clad externally with steel sheets and internally with $\frac{1}{2}$-in. cane fibreboard.

499. In Scotland the framing supporting the floors and roof and providing fixing for the cladding consisted of steel stanchions and horizontal members of angle section. In London steel stanchions and horizontal angles carried the first floor joists and wall plate. The sheets were bent to form horizontal stiffeners, the angles at these joints being omitted.

500. EXTERNAL CLADDING. In Scotland the external steel plates were approximately 8 ft. wide×3 ft. high and of 11 gauge (=$\frac{1}{8}$ in.) metal on the ground floor and 12 gauge metal on the first floor. The plates were bolted to the angle framing, the bolts being bedded in red lead and tow. The horizontal joints were made with a joggle joint and incorporated a canvas strip, impregnated with paint. The vertical joints were covered with a steel strip 6 in. wide, bedded on canvas similar to that used in the horizontal joints. The steel sheets were protected against corrosion on the inside by a coat of red-lead paint with a granulated cork finish. In London the construction was similar but with the following differences: all the sheets were approximately 8 ft.×2 ft. 6 in., the upper edges being bent to form horizontal angles; the stanchions were of T section, the web covering the

THE ATHOLL HOUSE



STEEL PLATES ON STEEL TEE FRAME. LINING OF FIBRE-BOARD ON WOOD FILLETS. WOOD FLOORING ON LAYERS OF BREEZE CONCRETE, CEMENT CONCRETE AND HARDCORE. ROOF CONSTRUCTION OF WOOD PURLINS AND RAFTERS ON STEEL TRUSS

vertical joints between the sheets. The internal face of the sheets was protected against corrosion by one coat of red lead and one coat of bituminous paint. The external finish was paint in both cases.

501. PARTY WALLS. In Scotland the party walls consisted of $\frac{1}{8}$-in. steel sheets faced both sides with wood fibreboard on studs. The chimney breasts and stacks were of clinker concrete blocks. In London normal 9-in. brick walls plastered both sides were provided. Chimney breasts and stacks were of brickwork in all cases.

502. The rest of the construction was conventional.

THE COWIESON HOUSE

503. The Cowieson system of house construction was developed by Messrs. F. D. Cowieson and Co., Ltd., and houses of this type were built as follows:

NO. OF HOUSES	SITUATION	DATE OF COMPLETION	OWNER
500	On a number of sites chiefly in South Scotland	1927	Second Scottish National Housing Co. (Housing Trust), Ltd.

A number of schemes have been inspected.

504. EXTERNAL WALLS. The external walls consisted of timber framing, clad externally with steel sheets and internally with fibreboard.

505. The external cladding was of 12 gauge steel sheets, protected against corrosion, on the inner face, by bitumen felt fixed with bitumen solution. Lapped joints were used at the horizontal junctions between the sheets and the vertical joints were covered with a steel cover strip of curved section. The sheets were painted externally.

506. The internal cladding was of $\frac{1}{2}$-in. wood fibreboard fixed to studding with wooden cover strips.

507. PARTY WALLS. The party wall was of timber framing, faced both sides with wood fibreboard. The chimney breasts and stack were of concrete cast *in situ*.

508. The rest of the construction was conventional.

THE TELFORD HOUSE

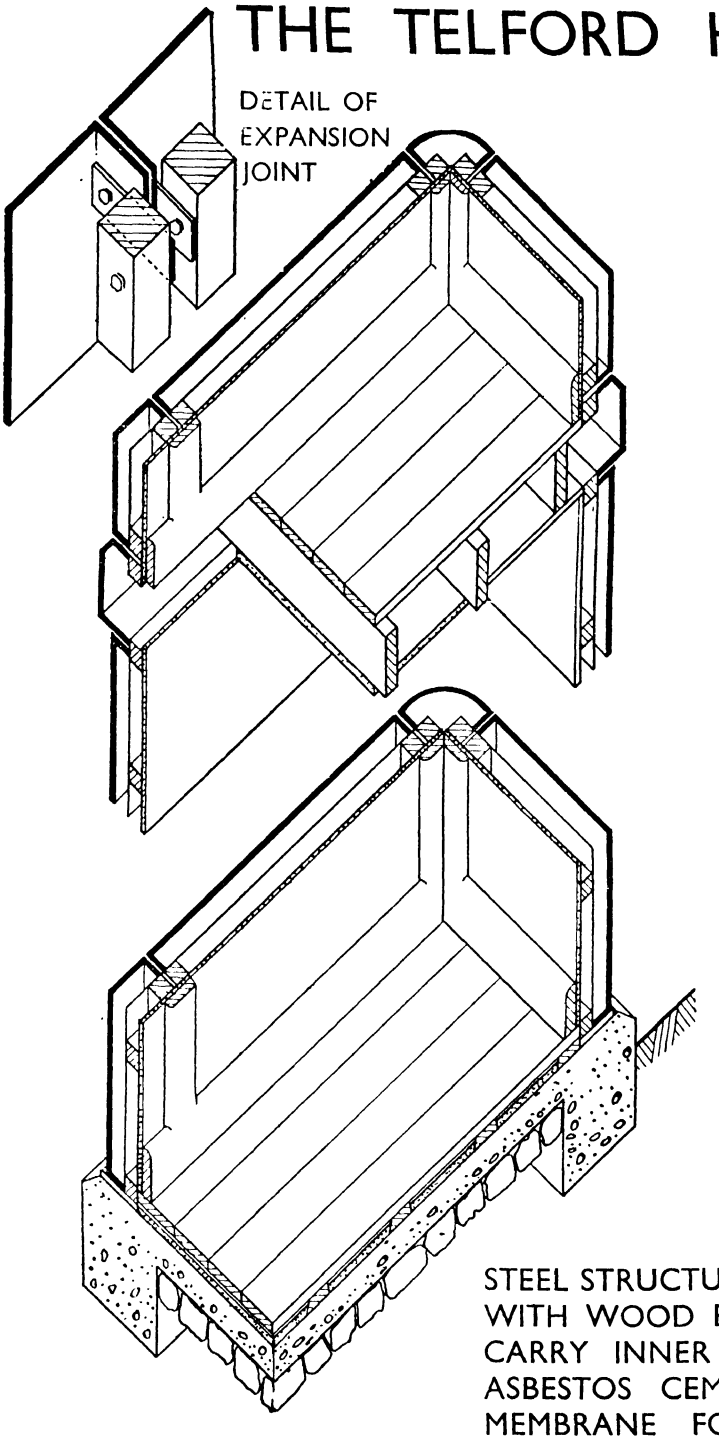
509. The Telford system of house construction was developed by Messrs. Braithwaite and Co. (Engineers), Ltd., and houses of this type were built as follows:

NO. OF HOUSES	SITUATION	DATE OF COMPLETION	OWNER
20	Bristol	—	Bristol Corporation
100	Bolton	—	Bolton Corporation
54	Hastings and a number of other sites	—	Hastings Corporation and various local authorities

The schemes listed have been inspected.

510. EXTERNAL WALLS. The external walls consisted of steel sheets formed into shallow "tray" sections, which acted both as external cladding and load-bearing members. The inner lining was of asbestos cement sheets on timber studs.

THE TELFORD HOUSE



STEEL STRUCTURAL PANELS WITH WOOD BATTENS TO CARRY INNER LINING OF ASBESTOS CEMENT. FELT MEMBRANE FOR INSULATION. UPPER FLOOR ON WOOD JOISTS

511. The external sheets were of 11 gauge sheet steel, 8 ft.×3 ft. 6 in. on face, with all edges formed into flanges (3 in. deep). The flanges of the sheets were bolted together to form stiffeners and supports of angle section. The sheets were protected against corrosion internally and externally with paint.

512. The internal lining was of $\frac{3}{16}$-in asbestos cement sheets on wood studs bolted to the steel sheets and the joints were covered with wood cover fillets.

513. PARTY WALLS. The party walls were of 11 gauge steel plate, faced both sides with asbestos cement sheets on timber studding. The chimney breasts and stacks were of 11 gauge sheet steel.

514. ROOF. The roof was of steel sheets as used in the walls, with steel hip and eaves pieces.

515. The rest of the construction was conventional.

EFFICIENCY OF STEEL-CLAD HOUSES

516. STRENGTH AND STABILITY. The stability of the walls in all types was adequate even under the severe conditions to which they were subjected on some of the sites.

517. MOISTURE PENETRATION. The steel cladding to external walls prevented moisture penetration. That there was no evidence of penetration indicated that the various methods of jointing the sheets were satisfactory. Dampness occurred, however, in roofs of the Telford type at the joints between the steel roof sheets and between the sheets and the eaves pieces, but as the roofs are subject to condensation (see Thermal Insulation) it is difficult to determine whether the moisture originated from inside or outside the roofs. At the points where moisture was most evident—*i.e.* at the flanged joints—the effects of condensation and leakage were likely to be equally pronounced. The type of joint used was not suitable as thermal movement of the roof sheets, with consequent straining of the joints, cannot be avoided.

518. THERMAL INSULATION. The computed coefficient of heat transmission for the external walls of the Atholl and Cowieson houses is 0·33. The insulation was thus inferior to that provided by an 11-in. unventilated cavity brick wall. Condensation troubles, however, were not experienced. The low thermal capacity of the thin lining of fibreboard made condensation unlikely; for the same reason the houses were likely to warm up more quickly than houses with plastered brick walls. However, it might take more heat to keep them warm on account of the relatively high heat transmission coefficient. Tenants agreed that the houses—especially the upper floors in flatted dwellings—were "rather colder" in the winter than brick houses, but not so much colder as to cause serious inconvenience. This apparent coldness might in part be accounted for by the absence of linings to the tiled roofs and the possibility of air leakage in the fibreboard ceilings.

519. The thinner wood pulp-board lining ($\frac{3}{8}$ in.) used in the Weir houses permitted higher heat losses than from the above types. However, the computed coefficient of heat transmission when the paper dividing the cavity into two is intact is 0·27—slightly better than for an 11-in. unventilated cavity brick wall. In practice damage occurred to the paper and the computed coefficient was thereby increased to a maximum of 0·43.

520. The asbestos cement linings to walls and unlined steel roofs of the Telford houses reduced the thermal insulation of the walls and roofs below that provided by the other steel-clad houses. The computed heat transmission coefficient for walls of this construction is 0·47. The houses were said to be cold in winter and hot in summer. Serious trouble from condensation was experienced on the asbestos cement wall linings and first floor ceilings. In cold weather condensation

on the steel roof was heavy and the water dropped from the flanges of the sheets. There was apparently no condensation on the inside surfaces of the steel wall cladding. The reason for this appeared to be that warm air from the house could not enter in appreciable quantities.

521. SOUND INSULATION. The estimated sound-reduction factor of the form of construction adopted in all types for party walls is about 40–45 db. This is unsatisfactory, and there is little doubt that the light construction permitted an objectionable degree of sound transmission. In many cases, however, the party walls divided the stairs and entrances of adjoining houses and the excessive sound transmission did not give rise to complaints. The 9-in. solid brick wall of the Atholl (London) type provided the normal pre-war standard of sound insulation between houses.

522. The sound-reduction factor of the light-weight stud partition walls adopted for all types is 40–45 db., which is considered adequate. It should be noted, however, that this sound reduction is not adequate for insulation against low-frequency sound.

523. FIRE HAZARD.

a. *Personal Hazard.* Except in the Telford houses, the untreated fibreboards used as linings to the external walls, partitions and ceilings constituted a personal fire hazard, because, in the event of fire, the rapid spread of flames across the surface of untreated boards might trap the occupants. The asbestos cement sheets used in the Telford type presented no more risk in respect of flame spread than do normal finishes in brick houses, but they are liable to shatter.

b. *Structural Hazard.* The only satisfactory party wall provided in any of these houses from the standpoint of structural hazard was the 9-in. solid brick wall in the London Atholl houses. In some Weir houses, the timber studding and wood-wool slab party walls originally used were later replaced by 2-in. clinker concrete blocks. This afforded some improvement, but cannot be considered satisfactory, since the degree of fire resistance afforded, measured as defined in *British Standard* 476–1932, is about one hour as compared with the suggested requirement of two hours.

c. *Exposure Hazard.* In those types having inadequate party walls the risk of fire involving a whole block accentuates the exposure hazard of adjacent blocks. Otherwise, although the hazard is somewhat more severe than in the case of a normal brick house, it calls for no special comment here.

524. VERMIN INFESTATION. Any form of construction which involves the use of sheet lining material with wood cover strips to the joints necessarily tends to add to the harbourage for bed-bugs. It is difficult, however, to assess the additional element of risk involved, in view of the amount of harbourage inevitably to be found even in the conventional brick house. No easy method of removing lining sheets was provided and disinfestation was not a simple matter in any of the types.

525. MAINTENANCE AND DURABILITY. When the houses were built doubts existed concerning the durability of the steel sheets and framing and of the asbestos cement tiles used in one type. During the inspection, therefore, particular attention was given to the condition of these materials.

526. In the early life of the Scottish houses there was considerable corrosion of the outside surfaces of the steel sheets, bolt heads and vertical cover strips, and it was considered that it would be necessary to repaint all the external steelwork every three years. However, in 1933 a method of painting (paint harling) was adopted which has been effective in preventing appreciable rusting since that date. A specification of this method is to be found in the Section on Paint in Part III of this Report. Most of the Scottish steel houses have been treated in this way

and the result has been entirely successful. Examination of a number of houses treated eight years ago failed to disclose any appreciable deterioration of the paint or corrosion of the steel sheets. The only rusting observed was an insignificant amount on some of the rounded heads of the bolts and drive screws used for fixing the sheets. The paint harling is still in such good condition that repainting is likely to be unnecessary for several years.

527. Corrosion of the cladding of the Atholl houses on the L.C.C. Watling Estate was not a serious problem. Since erection, the houses were only repainted on one occasion—some nine years ago—and it was then not necessary to clean the sheets to the bare metal or to apply more than three coats of paint. The paint will last for several more years. Small isolated rust spots were noticed, however. It appears, therefore, that adequate protection against corrosion can be obtained by normal methods of painting with suitable materials.

528. The inside surfaces of the steel sheets, where inspected, had not rusted. The various methods adopted by the manufacturers for protecting the internal surfaces of the sheets appear to have been effective, but it is worth notice that the conditions in the cavity between the sheets and the fibreboard lining were not conducive to condensation. Where the cavity was amply ventilated the liability to condensation was much the same as for an isolated free standing sheet.

529. Where the cavity was sealed, no condensation could occur provided the humidity of the air within the cavity was not greater than that of the outside air. Such conditions prevailed when there was no air leakage from inside the house through the lining. Serious leakage of relatively damp air from the house would have resulted in condensation.

530. In the Cowieson houses, after fifteen years, the half round steel strips covering the vertical joints of the steel sheets were found to be rusted through. Corrosion was said to be worse in this type of house than in others, and the suggestion has been made that the steel used was of a more corrodible type than normal.

531. There was evidence that the steel sheets in some Telford type houses built in England corroded, but it is considered that suitable painting or paint harling would have prevented this.

532. The other non-traditional material used in the construction of these houses —asbestos cement tiles, fibre and pulp-boards and asbestos cement sheets for lining—appeared to have given no trouble in respect of durability.

533. Some trouble was experienced with dry rot in ground floors and water penetration through tiled roofs, but there was nothing to indicate that these troubles were in any way connected with the non-traditional form of walling. Generally it may be said that the durability of all types gave no cause for concern.

534. GENERAL INFORMATION. Information obtained about initial and maintenance costs was of rather a general nature. It was understood that the 2552 dwellings (including flats, bungalows and houses) which were erected in Scotland cost an average of £500 each, and it would seem that, providing the painting of steel sheets can be restricted to about once in ten years, maintenance costs should be reasonable.

535. Where houses were not treated with paint harling their appearance was affected by the unfamiliar pattern of the steel sheets and of the bolt heads, etc., where these showed on the face. Paint harling imparted a texture to the steel sheets.

536. The survey established that steel sheets, when efficiently jointed, were a satisfactory external cladding; and that serious corrosion of the sheets was prevented by a suitable treatment of the surfaces.

537. Steel sheets contribute little to the functions of a wall except to the exclusion of rain, and because of this the other components of the wall must be chosen to provide the necessary strength and insulation. Criticism of steel-clad houses has been founded on the shortcomings of the wall constructions in some of these respects and not on defects in the cladding itself.

538. The use of steel sheets for roofs and party walls was not satisfactory. There is no reason why a sheet steel roof should not be efficient, if carefully designed for the conditions to which it will be subjected. It does not appear likely that sheet steel faced with wallboard is practical for a party wall construction if proper standards of sound insulation and fire resistance are to be attained.

THE THORNCLIFFE HOUSE

539. The Thorncliffe system of house construction was developed by Messrs. Newton Chambers and Co., Ltd., and houses of this type were built as follows:

NO. OF HOUSES	SITUATION	DATE OF COMPLETION	OWNER
2*	Mortomley	1927	Newton Chambers and Co., Ltd.
6*	Mortomley	1927	Wortley R.D.C.
12	Deepcar	1927	Stockbridge R.D.C.
20*	Hoyland	1927	Hoyland Nether U.D.C.
20	Annesley	1927	Nuneaton Corporation
500*	Allerton	1927	—

The schemes marked with an asterisk have been inspected.

540. EXTERNAL WALLS. The external walls consisted of flanged cast-iron plates, $\frac{3}{8}$ in. thick and 3 ft. square. Dovetailed keys were provided on the face of the plate, on to which was cast a $\frac{3}{4}$-in. thick layer of 1 : 3 (cement: sand) concrete, compacted by vibration. The plates weighed $1\frac{1}{2}$ cwt. before facing and the finished plate weighed over 2 cwt.

541. The plates were bolted together, through a wood fillet which projected on the inside and provided fixing for the internal lining; this was of asbestos cement sheets or fibreboard. The external joints were caulked with a bituminous material, and were pointed up with cement mortar. Special angle units were provided at the quoins.

542. The rest of the construction was conventional.

543. STRENGTH AND STABILITY. No calculations have been made by the Committee as to strength of walls; but as the houses stood satisfactorily for seventeen years with no sign of instability they may be considered adequate in this respect.

544. MOISTURE PENETRATION. The resistance to moisture penetration of the walls proved entirely satisfactory. Unsatisfactory design in detail of roofs and windows was responsible for some leakage, but the trouble was in no way connected with the form of wall construction.

545. THERMAL INSULATION. The computed heat transmission coefficient for the walls with asbestos cement lining is 0·46. The houses were said to be too hot in summer and too cold in winter, and condensation occurred on the walls, as would be expected when it is considered that the insulation provided is considerably below that of an 11-in. unventilated cavity brick wall.

546. The computed heat transmission coefficient for the walls of houses at Hoyland—lined with ½-in. wood fibreboard—is 0·29. This is rather better insulation than that provided by an 11-in. unventilated cavity brick wall, and the houses were said to be comfortable and not subject to condensation.

547. SOUND INSULATION. The party walls were of 9-in. brickwork and, therefore, the sound insulation provided was the same as for normal brick houses. The ground floor partitions were of 3-in. breeze concrete slabs—again fairly common practice. They are considered to provide adequate insulation as they have a reduction factor of about 40 db. The first floor partitions (studding lined both sides with asbestos cement sheets or fibreboard) were very light and are considered inadequate in respect of sound insulation.

548. FIRE HAZARD.

a. *Personal Hazard.* The asbestos cement sheets used present no greater risk of flame spread than do normal plaster finishes, but they are liable to shatter. As previously noted, however, the fibreboard lining used for some of the houses introduced a serious personal fire hazard.

b. *Structural Hazard.* The 9-in. brick party walls were a conventional and adequate fire stop between houses.

c. *Exposure Hazard.* The exposure hazard was less severe than with the steel-clad houses.

549. MAINTENANCE AND DURABILITY. There is no reason to doubt the durability of the cast-iron plates. Some rusting occurred where the plates were exposed through failure of the cement pointing between them, and also around window openings, but with cast iron this is not serious. Repointing did not result in excessive maintenance costs. There was some failure of rendering through impact, but again this was not serious.

550. VERMIN INFESTATION. The wall linings provided harbourage for bed bugs, and there was no easy method of removing the sheets for disinfestation.

551. GENERAL INFORMATION. The price of pig iron largely controlled the initial cost of cast-iron houses. The total weight of cast iron required for one house was about 7 tons (equivalent to about 94 sq. yds. of brickwork or, say, 9500 bricks). In 1927 cast-iron houses at Derby (with asbestos cement linings) cost some £15 more than brick houses with comparable accommodation. Later the cost of pig iron rose and cast-iron houses became uneconomical to build.

552. Semi-skilled engineering labour was employed in the erection of the cast-iron plates. As the finished plates weigh over 2 cwt. each they were not easy to erect without mechanical aid. It was stated that with suitable plant four men could erect the plates at the rate of one pair of houses per week.

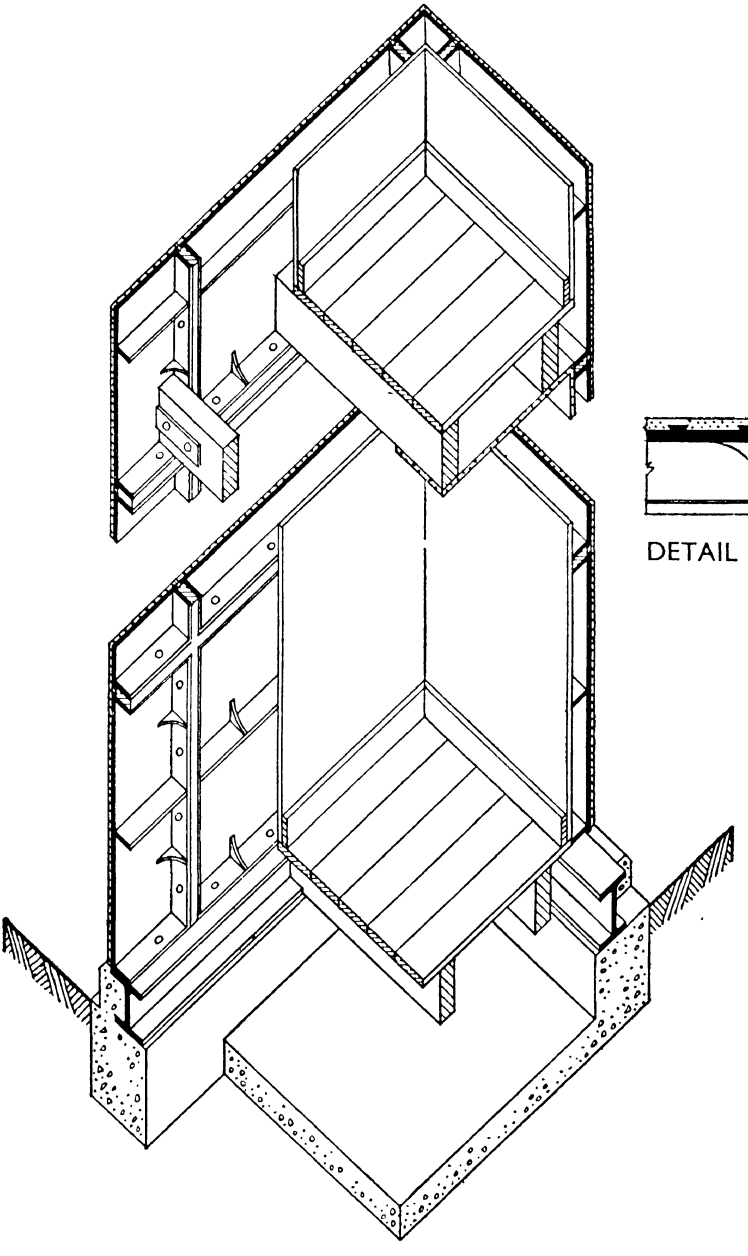
553. The only feature in the appearance of the houses which distinguished them from rendered brick houses was the pattern of the pointed joints between the plates.

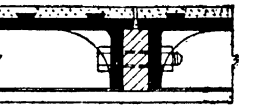
554. Local authorities stated that maintenance costs were the same as for brick houses.

555. These houses showed that cast-iron plates can fulfil some of the functions of external walling, namely, support and the exclusion of rain. As in the case of the steel-clad houses, if comfortable conditions are to be achieved, adequate thermal insulation must be provided by a suitable lining or by other means. This was not the case in the majority of these cast-iron houses.

556. The external finish was not entirely satisfactory; it added considerably to the weight of the units and increased maintenance costs on some sites. Some rusting

THE THORNCLIFFE HOUSE





DETAIL OF JOINT

CAST-IRON STRUCTURAL PANELS WITH VIBRATED CONCRETE. FACING EXTERNALLY. INNER SKIN OF PLASTERBOARD, ETC., ON WOOD FILLETS

followed the failure of the pointing between the plates, but this is not considered serious with cast iron.

METAL-CLAD WALLS

557. The most serious disadvantage of thin metal sheets for external cladding is that they contribute little to the thermal insulation of the wall.

558. The thermal insulation of the walls of steel-clad and cast-iron houses included in the survey depended upon a lining (of either asbestos cement sheets, wood pulpboard or wood fibrewood) in conjunction with an air space between the lining and the metal cladding. These lining materials possess the merit that they are easy to handle, but as used all suffered from certain serious defects.

559. Asbestos cement sheets in normal thicknesses have not a high degree of thermal insulation. The effects of condensation which may result are aggravated by the unabsorptive nature of asbestos cement, as compared, say, with lime plaster. There is also evidence that the decoration of asbestos cement has been difficult and expensive. The thin sheets ($\frac{1}{16}$ in.) are brittle and liable to damage by impact. As asbestos cement cracks and shatters under heat, it does not provide protection to the framing of buildings in case of fire.

560. Wood fibreboard has a high degree of thermal insulation. It is not brittle and the survey showed that it is durable. Untreated fibreboards introduce a serious personal hazard in case of fire. This can be avoided by treating the boards with silicate or other paints conforming to B.S./ARP 39 (*Testing Fire Retardant Timber Treatment by Exposure to the Action of an Incendiary Bomb*). Unfortunately, it is not easy to get as good a decorative effect with treated boards, as it is with untreated boards. The personal fire hazard is so serious, however, that untreated wood fibreboard cannot be recommended for linings.

561. In order to bring the thermal insulation of the walls of the metal-clad houses up to, or above, the standard of an 11-in. unventilated cavity brick wall it will be necessary to increase the insulating capacity of the lining, or to modify the construction of the wall. The first would entail using either a greater thickness of treated wood fibreboard (the $\frac{1}{2}$-in. thick sheets used in some steel-clad houses did not give the degree of insulation provided by an 11-in. unventilated cavity brick wall), or the use of some other suitable material in adequate thickness; the second might take the form of the incorporation of insulating air spaces. Notes on alternative materials for wall linings are to be found in Part III, para. 675 ff.

562. This problem of thermal insulation is likely to be encountered in walls of other thin sheet materials, *e.g.* asbestos cement.

563. Corrosion is an important problem in the use of metal sheets. In Scotland when the steel-clad houses were first erected, it was necessary to paint them externally every three years, to avoid corrosion. A method of painting, known as paint harling, overcame this difficulty; in England corrosion was prevented by normal painting methods. (A note on paint harling appears in Part III, para. 820 ff., which also deals with other methods of protecting steel.) A method of jointing the sheets so that bolt heads do not show externally appears to have advantages. If the sheets are flanged, as in the cases of the Telford house and the Thorncliffe cast-iron house, this is achieved.

564. The cast-iron plates in Thorncliffe houses were faced with cement concrete. It would be preferable to make no attempt to imitate the appearance of a rendered brick house, and freedom from corrosion and finish could be obtained by ordinary painting, or paint harling as for steel cladding. By omitting the concrete, the weight of the wall sections would be considerably reduced, the difficulties of pointing would be avoided, and the external surfaces would not be so liable to damage by impact.

PART III. NOTES ON MATERIALS

565. In Part I of this Report the basic technical requirements of house construction were considered in terms of strength, freedom from dampness, thermal insulation, etc., and in Part II the alternative forms of construction adopted in the inter-war period were reviewed in terms of these requirements. Some general conclusions were reached on these forms of construction and materials. It remains to consider the various types of material which may be available for use in post-war housing.

566. In recent years many new building materials have been developed and information has been accumulated on the general properties of these and older types and on their behaviour under practical conditions of use. Unfortunately, it has not yet been possible, in all cases, to compile quantitative test data sufficient to relate the materials directly to the basic requirements set out in Part I.

567. It is possible, nevertheless, to present in a comparative form the main features of the materials available for different purposes, and this is the aim of the notes given in the following pages. The intention is not to discuss traditional materials such as timber or brickwork but, rather, to concentrate on alternative materials of construction which may be used to supplement them. The notes do not purport to be exhaustive. These alternative materials are grouped under the following headings:

Damp-proof Membranes for Concrete Ground Floors.
Floor Finishes for Concrete or Steel Floors.
Wall and Ceiling Linings.
Light-weight Concrete Aggregates and Light-weight Concretes.
External Renderings.
Painting Requirements of Alternative Building Materials.

DAMP-PROOF MEMBRANES FOR CONCRETE GROUND FLOORS

568. The problem of insulating houses from ground moisture was discussed briefly in Part I, when it was explained how certain floor coverings such as linoleum or wood blocks are liable to become defective if laid direct on concrete which, in turn, is in direct contact with the ground. The remedy is to provide a damp-proof layer either within the concrete, at its surface, or underneath it.

569. Floor finishes are described individually in the next section of these notes, and it will be seen that not all of them require a dampcourse, as some types are themselves both impermeable to water and unaffected by it. Examples of these are: asphalt mastic, pitch mastic, rubber latex-cement, bituminous emulsion cement, clay tiles, concrete flooring tiles and granolithic and terrazzo finishes. The clay and concrete tiles and the granolithic finishes are, it is true, not entirely impermeable to moisture, but normally they are sufficiently dense to render its passage very slow and innocuous under the conditions in passages, kitchens, etc., where they would usually be laid. The other floor coverings described require dampcourses, and failure to provide them, or the use of inadequate forms, will often lead to subsequent troubles which are difficult and costly to remedy.

570. A dampcourse may be incorporated either beneath the base concrete, or within it as a "sandwich" layer or, in certain circumstances, at its surface, *e.g.* rubber latex-cement as an underlay for linoleum or rubber sheeting; a thick bitumen or tar coating for wood block or boarded floors. The present note is

concerned with dampcourses laid within the concrete slab to form a "sandwich" floor.

571. The concrete should be not less than 5 in. thick, the bottom layer being at least 3 in. thick and finished to a smooth surface on which the dampcourse is laid, followed by 2 in. of concrete. The base concrete should, preferably, be of a 1 : 2 : 4 mix, as with leaner mixes there is difficulty in obtaining a sufficiently even surface. This is important since irregularities in the surface may lead to puncturing of the dampcourse. The top concrete must be of a mix suitable for surfacing and capable of being finished smooth or be covered with a screed. The dampcourse, of which various types are discussed below, should be linked up with the dampcourses in the walls in such a manner that moisture cannot gain access to the top concrete at the edges of the slab.

572. TYPES OF DAMP-PROOF MEMBRANE

For dampcourses of the kind required, bituminous or tar products are almost exclusively used. Bitumen and tar products suitable for dampcoursing may be broadly classified as follows:

a. As asphalt or pitch mastic.
b. As dampcoursing (or alternatively roofing) felts.
c. As a coating with or without filler such as limestone dust, or in combination with stout building paper, and applied hot.

573. Asphalt mastic has long been recognised as a dampcoursing material even for tanking where it is necessary to withstand high water pressures. Bituminous felts were also much used as dampcourses in normal times, while the remainder have been used in war-time construction.

574. Supplies of bitumen have been restricted during the war, but, even if this should continue into the early post-war period, there are, as appears later, alternatives which should give satisfactory service.

MATERIALS FOR DAMP-PROOF MEMBRANE

The following is a brief account of the materials suitable for use as damp-proof courses:

575. ASPHALT MASTIC. Asphalt mastic is a well-recognised and eminently suitable material for dampcoursing and other waterproofing purposes. A specification (*British Standard* 1097–1943) covers asphalt mastic dampcourses composed of asphaltic bitumen, lake asphalt, and limestone, and the use of materials to this specification should ensure satisfactory service. Natural rock asphalt was widely used before the war in the highest grades of asphalt mastic, but is not obtainable during the war and is not yet covered by a British Standard.

576. Asphalt mastic dampcourses are laid hot in a minimum thickness of $\frac{1}{2}$ in.; details of the laying operations are included in *British Standard* 1097–1943. The operation requires skilful workmanship and is normally carried out by specialist asphalt firms.

577. PITCH MASTIC. In view of the growing shortage of bitumen during the war, coal tar pitch, of which there is an adequate supply, has been substituted for the bitumen employed in asphalt mastic. While the two resemble each other in general properties, pitch is more susceptible to temperature changes, becoming harder at low and softer at high temperatures, but this matters very little in the case of a dampcourse, the temperature of which remains fairly steady. The pitch mastics closely resemble the asphalt mastics for dampcoursing; the material is laid hot in a similar thickness and requires the same skill in technique. *British Standard* 1092–1943 covers the material and its preparation.

578. BITUMINOUS FELTS. Bituminous felt is a well-recognised material for various building purposes. It consists of a felt, composed of animal and vegetable fibre, which is saturated with a bituminous mixture composed of asphaltic bitumen or lake asphalt or suitable mixtures. This is then coated on both sides with a similar but harder mixture. The surface is treated with talc to prevent sticking in the roll. The standard weight is not less than 6 lb. per sq. yd., and the rolls are supplied in 3-ft. widths and not less than 24-ft. lengths.

579. Modifications of this type are also made, including the use of jute hessian or asbestos fibre in place of the animal/vegetable fibre felt, and also in combination with a thin lead foil sandwiched between two layers of fibre. Asbestos fibre is more desirable than animal and vegetable fibre which sometimes decays, though without necessarily impairing the efficiency of the dampcourse. Some types are heavier than the standard 6 lb. per sq. yd. The essential properties of the dampcourse are also reproduced in bituminous roofing felt of the "self-finished" type, which is, however, only about half the weight, but which can be used as an alternative to the types made specially for damp-proofing.

580. A description of these felts is given in *British Standard* 743-1941, *Material for Horizontal Damp-proof Courses*, where advice is also given on the selection of the various types. The factors which should be taken into account are site conditions, and the value, importance and intended life of the structure.

581. Probably more care is necessary in installing the felt type of dampcourse than with any other. The sheets must be properly lapped and sealed with the bitumen cement provided, and must not be allowed to become punctured, otherwise the whole object will be defeated.

ALTERNATIVE MATERIALS FOR DAMP-PROOF MEMBRANE

582. The foregoing dampcourses may be considered as those normally used before the war for good construction. For temporary work during the war-time, less substantial methods have been tried and these have so far been found to fulfil the purpose for which they were intended. Two of these war-time measures are described below. It seems reasonable to expect that they should give satisfactory service provided good workmanship is obtained.

583. PITCH FELTS. As in the case of asphalt mastics already described, coal-tar pitch has been substituted for bitumen used for saturating and coating the felt. A crude form of the felt was at one time made but fell into disuse when bituminous products became available. As a result of later developments pitch felts very similar to certain bituminous felts are now being made, and for these pitch felts a specification, *British Standard* 1067–1942, was drawn up. The felts are of one type only, viz. an animal and vegetable fibre felt saturated with a suitable coal-tar pitch with sufficient excess to hold a layer of sand over the whole surface. The weight of the finished felt is not less than 8 lb. per sq. yd. The same special precautions to ensure proper lapping and sealing and to avoid damage during laying are necessary as for bituminous felts.

584. BITUMEN OR COAL-TAR PITCH. Before the use of asphalt and felt dampcourses became widespread a somewhat crude method of damp-proofing was employed, consisting of treating the footings of walls with crude tar, sometimes in conjunction with a sheet of paper. Better results can be obtained by the use of bitumen or coal-tar pitch applied in a hot condition over the surface of the bottom part of the concrete slab. It will lose its effectiveness if the waterproofer is not prevented from running into the concrete, and therefore the surface upon which it is applied should be dense and smooth. A useful precautionary measure is to lay a sheet of stout building paper on the concrete before the dampcourse is poured. Mere blackening of the surface with the bitumen or pitch is insufficient,

and a layer with a minimum thickness of about $\frac{1}{8}$ in. should be required. As a general criterion, the layer should be smooth and continuous. Bitumen of softening point 50–55° C. or pitch of softening point 35–40° C. should be suitable.

585. Some advantage may be gained by the addition of a quantity of very fine mineral matter, to act as a stiffener or stabiliser. Certain proprietary mixtures of this nature are marketed, the material resembling the bitumen or pitch itself in general properties and not the mastics previously described.

FLOOR FINISHES FOR CONCRETE OR STEEL FLOORS

586. Consideration has been given to the question of finishes which would be suitable for concrete or steel sub-floors, should they be required as alternatives to timber or wood-block floors. The purpose of the present note is to give a brief survey of the type of floor finish which may be available.

587. For convenience the floor finishes have been grouped in two general classes, jointless and jointed. The nature and properties of the individual materials are described and in each case notes are given on special precautions needed in laying and maintenance to ensure satisfactory service; suggestions are also made as to the uses for which each flooring material is best suited in post-war housing. It is realised that in some cases the finishes may be expensive, but since it is difficult to forecast what their relative costs will be after the war it has seemed undesirable to exclude any of them on this ground. The costs can be compared at the time when the actual choice has to be made.

588. It will be observed that in nearly every case the notes lay stress on the need for skilled operatives and adequate supervision in laying the floor. Investigation of cases of failure has shown that a large proportion of them have arisen either through carelessness in laying or through failure to appreciate the need for certain precautions, *e.g.* the provision of a dampcourse in concrete ground floors where the flooring is of a type which is affected by moisture.

589. Considerable importance is also attached to the ease of cleaning and maintenance of floors. Many of the floor finishes described require periodic polishing to maintain in good condition, and if this is given, the surface should give a satisfactory service. Washing with water alone, or water and soap, according to the type of surface, will not cause damage, but some of the surfaces are likely to deteriorate if subjected to constant scrubbing. For kitchens and passages the floor surfaces which can be regularly scrubbed may be preferred by many householders, but for living rooms and bedrooms this drastic form of cleaning is less essential and the prime requirements are more those of warmth, resiliency, quietness and ease of maintenance.

590. Some of the materials described are not available for flooring at present, notably rubber, bitumen, magnesite and cork, while others, such as linoleum, are in very limited supply. It is hardly possible at present to predict what the supply position of these materials will be in the immediate post-war period, but magnesite at least, and it may be hoped bitumen and linoleum, should become more readily available.

JOINTLESS FLOORS

MAGNESIUM OXYCHLORIDE FLOORING COMPOSITION

591. Magnesium oxychloride or, as it is frequently called, magnesite composition flooring consists essentially of a mixture of burnt magnesite with fillers and pigments which is gauged with a solution of magnesium chloride. The latter combines with the burnt magnesite to form a strong cement. The fillers generally

consist of sawdust and/or wood flour and, sometimes, a portion of talc, asbestos or sand.

592. The materials for use in the manufacture of the composition are to some extent covered by *British Standard* 776–1938, but at present the specification does not closely define the properties of the burnt magnesite, although it is hoped that this will be done later. The pigments are covered by *British Standard* 1014–1942.

593. The *Code of Practice for the Laying of Magnesite Composition Flooring and Dadoes*, published by the Building Industries National Council in 1938, describes in detail the requirements for sub-floors and the methods of mixing, laying and maintaining the composition, and it also specifies tests for the mixes used. It is essential that this Code should be followed if satisfactory results are to be obtained. Among the requirements laid down the following may be noted: the sub-floor shall be rigid, dry and not too porous. Good-quality concrete made with dense aggregate forms a very suitable base, but weak concretes or those made with porous aggregate are unsuitable. Concrete slabs in contact with the ground must contain a dampcourse. When used in proximity to metal such as on steel or reinforced concrete bases, rigid precautions must be taken against the corrosive action of the magnesium chloride. The best results are obtained only when the flooring is laid by skilled operatives with efficient supervision. Subject to these provisions magnesite composition is suitable for use on many types of sub-floor, *e.g.* concrete, steel, stone, brick or wood.

594. Magnesium oxychloride floors require regular maintenance if long life and good appearance are required. The maintenance, however, need not be high. A surface treatment with a wax polish or linseed oil at six-monthly intervals will probably prove quite satisfactory in most cases. They should be kept clean by scrubbing with warm water only. A mild soap may occasionally be used, but no soda or washing powder containing soda should be employed.

595. The floor, if properly maintained, is free from dusting and splintering and is reasonably easy to keep clean. It is moderately warm, possesses good wearing qualities, but is rather hard and noisy. It is unaffected by mineral oils and greases or vegetable fats; when wax polished it tends to become slippery; the floor is well adapted to forming coved skirtings and should be proof against bug infestation.

596. In the past, the reputation of magnesite composition floors has suffered by reason of numerous failures, but there is little doubt that a high proportion of these were due to the floors being laid at cut prices with unskilled labour and insufficient supervision. As examples of the defects which have arisen due to these causes the following may be cited: severe cracking and low wear resistance; insufficient protection of metal-work leading to severe corrosion with its consequent troubles; disintegration due to laying the floor finish on an unsuitable base, the base being either too weak or not containing a damp-proof membrane; severe "sweating" of the floor generally due to the use of too wet a mix and excess of magnesium chloride; trouble due to damp walls owing to severe contamination with magnesium chloride resulting from careless mixing.

597. It was to overcome such troubles as these that the Code of Practice was designed, and it is therefore felt that, with the appropriate precautions, there is no reason why the material should not take a useful place in post-war housing. The most suitable situation for its use would be living rooms, bedrooms and halls. It is not recommended for kitchens or bathrooms where it may be exposed to high humidity or damp conditions. If, however, it is found necessary to use this floor for such situations the surface should be adequately protected by wax-polishing or oil treatment.

MASTIC ASPHALT FLOORING

598. The materials which may be used in mastic asphalt flooring include natural rock asphalt, lake asphalt, natural bitumens, asphaltic bitumen and oils obtained from petroleum, fine graded limestone and a coarse siliceous grit. The natural rock asphalt has not been available for general flooring purposes during the war, but in 1942 *British Standard* 1076–1942 was issued for the asphaltic bitumen/lake asphalt/limestone type. It is expected that a specification for the natural rock type will be prepared later so as to be ready for use when this material is once more available. No standard specification exists at present for coloured asphalt.

599. Mastic asphalt is generally delivered to the site in blocks of about ½ cwt. These are broken up and remelted in appropriate mixers; frequently the coarse aggregate is added during this stage. When the mixture has been heated to the proper temperature it is spread, whilst hot, to the desired thickness (not less than ½ in.) over the sub-floor. As for many other jointless floor finishes, skilled operatives and efficient supervision is essential if unsatisfactory floors are to be avoided. This material can be laid on most types of bases. In order to isolate the mastic asphalt from the base floor and thus avoid "blowing" of the mastic during laying, the base floor may be sprinkled with a fine dry powder such as ground limestone or rock asphalt, or covered with a black sheathing felt. In cases where the mastic asphalt is laid on a timber foundation, the use of a felt isolating membrane is essential and should be provided for in the specification.

600 Mastic asphalt flooring, in various colours, has been used successfully for many purposes. No damp-proof membrane is necessary in ground base concrete as the mastic asphalt is itself impermeable to moisture in any form; and it is unaffected by contact with moisture. The floor finish is moderately warm, free from splintering or dusting (though this latter defect is occasionally encountered in coloured asphalts), and is reasonably easy to keep clean. Mineral oils or greases and vegetable oils or fats soften the bitumen and thus may lead to gradual disintegration. It is not too noisy and it can be obtained in varying degrees of hardness to suit different conditions, but depressions are formed over long periods by heavy weights. The wearing qualities of a properly laid floor are good and it shows little tendency to form unsightly cracks. The floor is well adapted for coved skirtings and should be proof against bug infestation.

601. If improperly laid, mastic asphalt mixtures are liable to a number of troubles —for example, formation of blisters with consequent failure, formation of cracks resulting from overheating of the mastic, and dusting when unsuitable mixes are employed.

602. Mastic asphalt floors require regular maintenance to preserve good appearance. They can be washed with warm water and soap but not with soda or cleaning powders containing soda; they take polish easily, but special polishes suitable for asphalt floors must be used.

603. In post-war housing this flooring should prove satisfactory for living rooms, bedrooms, halls and bathrooms. Generally, for kitchens in private dwellings asphalt flooring should be satisfactory, but failure is likely if the floor is heavily contaminated with oils or fats.

PITCH MASTIC FLOORING

604. Pitch mastic for floor finishes is based on coal-tar pitch and either calcareous or siliceous aggregate. A British Standard for this material, namely *Pitch Mastic Flooring* (*British Standard* 1093–1943) has recently been issued. In many respects this flooring resembles, and can be looked upon as suitable alternative to, mastic asphalt. The precautions regarding laying are similar to those required for asphalt.

605. In general, the properties are similar to those given for mastic asphalt, although there are, however, some exceptions. It is less affected by mineral and vegetable oils, fats and greases, and therefore is not so liable to be damaged by contact with these materials. It takes polish easily and any type of wax polish can be employed, although it is preferable to use special polishes as for asphalt. Although the material has only comparatively recently been used to any extent as a floor finish, observations so far made show that good wearing qualities are to be expected from well-laid pitch mastic floors.

606. The types of failures to be expected with improperly laid pitch mastic floors are similar to those mentioned with mastic asphalt and the same precautions are required. Special care is, however, needed in laying not to overheat the material.

607. This floor finish requires similar maintenance to mastic asphalt finishes.

608. In post-war housing the material should prove satisfactory in technical performance for living rooms, bedrooms, bathrooms or kitchens.

CEMENT-BITUMEN FLOORING

609. Cement-bitumen for flooring is essentially a mortar in which the mixture of cement and fine aggregate is gauged with bitumen emulsion instead of with water. Any inert aggregate which is resistant to abrasion can be used; the maximum nominal size should not be greater than $\frac{1}{8}$ in.

610. The proportions of cement and aggregate are of the order of 1 part cement and 3 parts aggregate, with sufficient bitumen emulsion added to give a semi-plastic mix. The final mix contains approximately 7–10 per cent. of bitumen. Care is required in the control of the proportioning and mixing in order to obtain good and reproducible results. This can be ensured by delivering to the site in containers proportionate weighed amounts of each constituent.

611. The flooring is laid cold, to a minimum thickness of $\frac{1}{2}$ in., over the base. The material can be laid over a variety of sub-floors as, for example, concrete and steel. Before laying, the base should be thoroughly cleaned and then painted over with a coat of bitumen emulsion. The finish is laid immediately after the emulsion, smoothed to the desired level with a steel trowel and later finished by trowelling just when initial set occurs. To get the best results skilled operatives and efficient supervision are required. The floor is damp-cured for at least 24 hours, surface treated and polished. It should not be opened to traffic for some days.

612. Cement-bitumen floor finishes have been used for some years and may be obtained in various colours. The pigments should conform to the *British Standard* 1014–1942, *Pigments for Cement, etc.* The floor is free from dusting and splintering and is reasonably easy to keep clean. It takes polish easily, but special polishes must be used. It is reasonably non-slip. As for mastic asphalt, mineral and vegetable oils, greases and fats soften the bitumen present and thus lower the wearing qualities. It is not hard—again, as for asphalt, heavy weights indent the floor—and not very noisy. In this latter respect it is better than concrete, asphalt or wood-block flooring, but is not so good as linoleum. The wearing qualities are good and the floor shows little tendency to produce unsightly cracks. It is not appreciably affected by water, and it is thus safe to use this floor finish on ground concrete bases which have no damp-proof membrane. It has a lower thermal conductivity than asphalt and is therefore a warmer floor, and should be proof against bug infestation.

613. To obtain satisfactory results it is essential that suitable mixes of cement, aggregate and bitumen be used. It should be emphasised that no less skill is required in laying than with other jointless floors. As with them, also, regular

maintenance is needed to maintain a good appearance. In view of the bitumen content care must be taken that suitable polishes are employed unless the floor has been specially surface treated to enable any polish to be used. The floor can be washed with warm water and soap, and even with no further maintenance it can retain a reasonable appearance.

614. Cement-bitumen flooring should prove useful for post-war housing. It is suitable for use in living rooms, bedrooms, halls and bathrooms. It is, however, less satisfactory for use in kitchens unless it can be sufficiently protected against the effect of fats and greases. This protection may be obtained by occasional surface treatment with certain of the synthetic resins.

GRANOLITHIC AND TERRAZZO FLOORING

615. Granolithic flooring is the term generally applied to fine concrete floor finishes having a special hard-wearing aggregate such as granite. This finish is laid either: a. on base concrete before this has hardened; in this case a minimum thickness of $\frac{3}{4}$ in. would be required; b. on a hardened base concrete; the thickness in this case is usually $1\frac{1}{2}$ in. to 2 in., but 1 in. has been reported to have been used successfully under housing conditions. Where 2-in. thickness is laid it is sometimes the practice to place this in two courses, the first semi-dry and the last $\frac{1}{2}$ in. with a rather wetter mix. The hardened surface of the base concrete has to be roughened, well cleaned and wetted to ensure an adequate bond, and cement grout should be brushed over the concrete surface immediately before laying. When the floor is laid in two layers, the topping is placed immediately the base layer has been levelled off with a straight-edge.

616. The wearing surface consists generally of either 1 part cement to $2\frac{1}{2}$ parts (by volume) of granite or other hard-wearing aggregate, or 1 part cement, 1 part sand and 2 parts aggregate. In each case the aggregate should be free from dust passing through 100 mesh sieve. The amount of water used should be the minimum required to give the necessary plasticity for laying. The floor is finally trowelled off to a smooth finish.

617. Terrazzo floors are similar to granolithic floors except in that a decorative stone such as marble is used as aggregate, usually with a white or coloured cement, and the surface is finished by buffing and polishing to develop the appearance of the aggregate.

618. Floors of both types, if properly laid, are hard, reasonably dust-free and of excellent wearing quality. They are, however, noisy and cold. A well-finished surface is easy to keep clean; it does not scratch easily and household cleaning powders can be used without fear of damaging the floor; when polished, however, it becomes very slippery. Although these types of flooring are slowly attacked by vegetable oils and fats, the effect under domestic conditions should be negligible. They should be proof against bug infestation.

619. If improperly laid, granolithic floors are liable to suffer from surface dusting, cracking and loosening from the base. Skilled operatives should be employed and the floors cured wet for some days before being opened to traffic. Inadequate preparation of the base, the use of too wet mixes often combined with the subsequent application of dustings of dry cement, and error in judging the most suitable times for the trowelling operations are the commonest causes of unsatisfactory results. Joints in the flooring should coincide with joints in the sub-floor. A surface treatment with sodium silicate solution or other surface hardener is often applied after the floor has hardened and is a useful method of improving the wearing properties and reducing the tendency to dusting. For merely domestic traffic, however, such a treatment is only required on surfaces which have been imperfectly laid or finished.

620. The above remarks apply in some degree to terrazzo except that, owing to the surface being buffed, dusting is seldom a problem and hardening treatments are therefore unnecessary. With this type of finish it is usual to divide the floor into small areas by means of strips of ebonite or some other inert material to minimise cracking.

621. In post-war housing granolithic floors should prove satisfactory for kitchens, sculleries, lavatories (outdoor) and halls. It is too cold a floor for main living rooms or bedrooms. Similar comments apply to terrazzo, but this is less likely to be used on account of cost.

(*Note.* The painting of concrete floors is discussed later in the general section on painting.)

CEMENT-WOOD FLOORING

622. Mixtures of sawdust with Portland cement have been used to a limited extent for a number of years, but they have not been successful for flooring purposes because they frequently crack or lift from the base. Recently, further experimental work has been carried out with a view to producing a satisfactory flooring mix.[1] This work has shown that a mixture of Portland cement, inert aggregate, such as limestone or silica sand, and sawdust can give a flooring which is reasonably free from the defects normally associated with ordinary cement-sawdust mixes.

623. Suitable mixes are 1 part cement : 1½ parts aggregate : 1½ parts sawdust (all by volume) or 1 cement : 1 aggregate : 2 sawdust. Some types of sawdust, mainly those from hard wood, affect the setting and hardening of the cement, but this difficulty can be surmounted by a suitable pre-treatment of the sawdust. Generally with soft-wood sawdust no pre-treatment is required if a proportion of hydrated lime is added to the mix.

624. The mixes can be laid on concrete or wood bases provided these are rigid. It is uncertain whether they can be laid on steel floors. When laying on timber floors it is advisable to fix wire-netting to the base before placing the mix. When laid on concrete, the usual precautions for cleaning the base must be taken and a stiff cement slurry should be brushed into the surface of the base immediately before laying the finish. The constituents are first thoroughly mixed dry and water is added to give an earth-moist consistency. It is imperative for the water content to be kept as low as possible. The mix is laid in position by the usual method for jointless floor finishes, well-tamped and smoothed off with a steel trowel. With the correct consistency of mix it should be possible to produce a smooth finish without working any cement laitance to the surface. A second trowelling just before the mix hardens is an advantage. The floor should be damp-cured for at least 24 hours after laying and should not be walked on for 48 hours. When the mix has dried it should be given a surface treatment with linseed oil or wax. As for other jointless floors, skilled operatives and efficient supervision are required for laying.

625. These cement-sawdust mixes can be prepared in various colours giving floors of good appearance. The pigments used for coloured floors should comply with *British Standard* 1014–1942, *Pigments for Cement, etc.* The floor is free from dusting and is relatively easy to keep clean. It is of medium hardness and quietness. When properly laid it shows little tendency to produce unsightly cracks. It gives a reasonably warm floor. At present there is insufficient information regarding its wearing properties, although from the limited data available it is expected that it should be suitable for domestic use at least. It should not be used in damp situations and therefore, if used on concrete floors on the ground, a damp-proof membrane is required in the base floor. When well polished it tends to become slippery.

[1] A provisional patent application has been filed.

626. If improperly laid the flooring is liable to crack or lift from the base. If too little care is exercised regarding the pre-treatment of the sawdust, or in laying, weak floors of low wearing qualities are likely to result.

627. Cement-sawdust floors require an occasional treatment with linseed oil or wax polish to preserve a good appearance. They can be washed with soap and water, but it is not advisable to use soda or powders of soda content or to scrub them.

628. This type of floor should prove satisfactory for living rooms and bedrooms in post-war housing. It cannot be recommended for use in kitchens, bathrooms or situations where it might be exposed to damp conditions.

CEMENT-RUBBER LATEX FLOORING

629. In the years before the war considerable use was made of floors incorporating rubber latex with mixtures of cement, aggregates and fillers. Various mixes have been used in which the rubber content varied from 4 per cent. to 12 per cent. by weight. High alumina and Portland cements have been employed, while a great variety of aggregates have been incorporated to give different finishes.

630. The flooring adheres very firmly to almost any type of sub-floor. On clean concrete the mix is laid direct with no pre-treatment of the base; on steel a preliminary slurry of latex and cement is required. The standard thickness of flooring varies from $\frac{3}{16}$ in.–$\frac{1}{4}$ in. It should be damp-cured for the first 24 hours after laying and it should not be opened for traffic for 48 hours. For the better-class floors the surface is buffed and then polished.

631. Floors of good appearance in various colours and different types of decorative or utility finishes can be prepared which have good resistance to wear. These floors are quiet, resilient and comfortable to walk on without showing any tendency to dust or crack. They are moderately warm, resembling linoleum in this respect. They are not difficult to keep clean although not so satisfactory as some other jointless floors. The difficulty is the tendency for dirt to become engrained in the surface which without regular maintenance becomes very drab. It is moderately non-slip even when regularly polished.

632. This type of floor may be used in damp situations without any particular precautions. It is well adapted to the formation of coved skirtings and is proof against bug infestation.

633. It should be emphasised that satisfactory floors cannot be obtained by simply using a rubber latex solution as a gauging liquid for a normal cement mortar mix. It is essential therefore that the flooring mix should be supplied and laid by a firm with experience of this type of flooring.

634. Rubber latex-cement flooring requires maintenance by regular washing and wax-polishing for good appearance. It should be found satisfactory alike for living rooms, bedrooms, and for kitchens, bathrooms and halls.

CALCIUM SULPHATE FLOORING

635. Floor finishes in which calcium sulphate forms the major binder have not been much used in this country. In Germany, on the other hand, they have been used for many years, mainly as an underlay for linoleum, but also as the wearing surface for light traffic such as in houses, factories and certain types of agricultural buildings. These floors are laid under rigid supervision, and a detailed specification was issued regarding the type of calcium sulphate (Estrich Gips) to be used and the precautions to be taken in laying. Recently in this country a flooring mix has been developed which consists essentially of natural anhydrite binder containing

an accelerator with natural anhydrite aggregate. The mix is one part aggregate, $\frac{3}{16}$ in. nominal size with one part binder by volume, and this is gauged with the minimum amount of water to give the necessary consistency for laying. The sub-floor, if of concrete, is first primed with a slurry coat of the binder. On a timber sub-floor a layer of wire-netting or light expanded metal is first fixed to the base and the flooring laid over it. This calcium sulphate floor should be damp-cured for the first 24 hours and should not be exposed to traffic for at least 48 hours. After the floor has thoroughly dried it should be given a surface impregnating treatment with linseed oil diluted with white spirit. The thickness of the floor-covering should not be less than $\frac{1}{2}$ in. Skilled operatives and efficient supervision are required for laying satisfactory floors.

636. Floors of good appearance and of various colours are possible with this mix. With the coloured floors scratches tend to show up as white marks, but after the original surface skin has worn away the aggregate grains appear in their original colour and so produce a mottled appearance and scratches then become less evident. More deliberate decorative effects may be obtained by abrasive treatment to expose the aggregate. The floors are not very dissimilar from concrete in respect of hardness, coldness and noise. Information regarding the wearing qualities is, at present, limited, but what is available indicates that resistance to wear is sufficiently high for a number of purposes in post-war housing. Continued dripping of water will soon produce a deep depression in the floor surface, but such depressions can be repaired with fresh mix. It should not be used in permanently damp situations and therefore, if laid on ground concrete floors, a damp-proof membrane is required in the base floor. The floors should be free from shrinkage cracks and do not dust readily, and in these respects they have advantages compared with many concrete floors. The mix is quite suitable for forming coved skirtings and should be proof against bug infestation. The calcium sulphate binder has a slight corrosive action and metals which might come into contact with the material must be adequately protected.

637. Calcium sulphate floors require regular treatment with linseed oil diluted with white spirit to give the best results. The floors may be washed with soap and water but should not be too frequently scrubbed. Soda and household cleaning powders should not be used.

638. This flooring should be suitable for living rooms but it is considered that it may be too cold for use in bedrooms, and it cannot be recommended for bathrooms, kitchens or any situation where it would be exposed to damp conditions for long periods.

JOINTED FLOORS

LINOLEUM

639. Linoleum, probably the most widely known and used of all floor finishes, is based on a cork or wood-flour matrix. It consists of linseed oil, gums and resins, cork dust and/or wood-flour, and pigments, and the mixture is applied while hot to a woven jute backing. The backing is sufficiently open to provide a strong mechanical key. The material is then subjected to controlled curing.

640. Linoleum is supplied in sheet form in rolls 6 ft. wide, 30–90 ft. long and 1·9 to 6·7 mm. thick. There is a *British Standard* 810–1938 for plain linoleum which deals with types and qualities—the quality is based on thickness only. There is no specification for inlaid or jaspe linoleum.

641. Linoleum may be laid on concrete, steel or wood sub-floors which should be rigid, level and dry, otherwise its life is impaired. Before placing the linoleum it is common practice first to spread it flat over the floor for a few days. With the cheaper grades the linoleum is usually laid loose on the floor, but the most satis-

factory method is to fix it to the sub-floor over the whole surface with a suitable adhesive.

642. A large variety of colours and patterns is obtainable with linoleum. The surface is easily cleaned, does not dust or splinter, and in the lighter shades and patterned finishes does not show footmarks; when highly polished it tends to become slippery. Unless it is stuck down it tends to spread and form ridges when subjected to heavy traffic. It is not hard and heavy weights produce depressions in time; boot nails also tend to produce slight depressions. The floor is fairly quiet and warm, but it is susceptible to dampness, and if kept in contact with a damp sub-floor it tends to blister and finally fail under traffic; this is one of the most prevalent causes of failure of linoleum. It is essential therefore to ensure that the sub-floor is dry and free from dust, and for concrete ground floors a damp-proof membrane should be incorporated; in this respect reliance should not be placed on the adhesive agent behaving as a satisfactory membrane.

643. To maintain a good wearing surface it is advantageous to paint new linoleum with boiled linseed oil and, when this has dried, to wax-polish. Thereafter wax-polishing is sufficient. Ordinary cleaning requires only soap and water.

644. Linoleum should be a satisfactory flooring for living rooms, bedrooms, kitchens and halls. For bathrooms particular care is desirable to ensure satisfactory jointing and adhesion to sub-floors.

CORK CARPET

645. This material is essentially the same and is prepared by the same processes as linoleum, except that it contains no wood-flour and the cork used is more granulated. The qualities are defined in *British Standard* 810–1938, *Part* 2. The general properties are very similar to those already mentioned for linoleum. It is quieter under tread, but it is also much more absorbent and therefore more difficult to clean. Its use in kitchens is not to be recommended.

CORK TILES

646. Cork tiles are prepared by heating granulated natural cork under pressure without the use of any binding agent. No colouring matter is added, but various shades of rich brown are available as well as a bleached light brown. The standard sizes are 6 in. to 18 in. square, with thicknesses varying from $\frac{3}{8}$ in. to $\frac{9}{16}$ in.; the tiles may be either tongued and grooved or square-edged.

647. The tiles may be laid on either wood or concrete floors, but it is not certain that steel would be an entirely satisfactory base. In all cases the sub-floor should be dry, rigid, smooth and level. The tiles are fixed by means of an adhesive which is generally of the bitumen type. Frequently a felt underlay is used, especially with timber sub-floors, and the tiles are fixed with panel pins either to the timber or in the case of concrete to a special screed which is capable of holding nails.

648. These floors are of pleasant appearance, wear well, are soft, resilient and almost noiseless. Even when polished they are non-slip: they are absorbent and thus if not properly maintained will become very dirty. Coved skirtings and stair nosings can be made.

649. Considerable skill is required in laying cork tiling, and it must be protected from rising damp and penetrating oils and fats.

650. The usual cleaning method is polishing with a liquid wax emulsion, though the surface should be washed occasionally.

651. Living and bedrooms are suitably placed for this type of floor, but it is not recommended for kitchens or bathrooms.

RUBBER FLOORING (SHEET AND TILE)

652. In recent years rubber has been used to a considerable extent as a floor covering. It can be obtained in sheet or tile form and is manufactured from a mixture of rubber and various fillers, specially treated and vulcanised. Rubber sheet may be prepared in two different ways; in the first method the sheeting is made and finished on a drum, while in the second the sheets are finally finished under high pressure which gives the material a smooth impervious surface. This latter type of sheet is sometimes known as "tiling" or "press-finished."

653. The rubber sheet or tiles may be obtained in various thicknesses from $\frac{1}{8}$ in. to $\frac{3}{8}$ in.—the latter thickness being used mainly for very heavy wear. Rubber floors may be laid on a variety of bases if the latter are dry, rigid and level. If laid on concrete this should be furnished with a screed floated smooth and allowed ample time to dry thoroughly. With ground concrete sub-floors a damp-proof membrane must be incorporated in the base. It is rather more difficult to obtain good adhesion to steel floors, but this can be done satisfactorily as long as the steel presents a continuous surface. The rubber is fixed to the sub-floor by means of a rubber cement, and for good adhesion the surface of the sub-floor should be free from dust.

654. Rubber for flooring may be obtained in a variety of colours. The material does not dust or splinter; it is easily cleaned by simple washing with soap and water, but if a cleanser is used it should not have any abrasive action; it is very quiet and resilient; with plain colours it tends to show marks easily, but this tendency is not so pronounced with the mottled or marbled finishes; it is non-slip, but since oils and greases have a deleterious effect on the rubber it is advisable to use special polishes for surface treatment. Where it is subjected to heat from heating appliances special heat-resisting cements should be used for fixing. It should not be used in damp situations. The wearing qualities of a well-laid floor are good, but a permanent depression tends to form under prolonged static loading.

655. To lay satisfactory floors it is essential to provide skilled operatives and efficient supervision. Unless this is done trouble may be experienced especially with the thinner material.

656. Manufacturers usually issue their own recommendations for maintenance. Generally the floor should be washed with soap and water, but it is also desirable that it should be wax-polished periodically.

657. Rubber floors should be satisfactory in post-war housing in living rooms, bathrooms and bedrooms, but would not usually be recommended for kitchens or any situation in which they would be exposed to permanent damp conditions or where rising damp may come into contact with them.

COMPOSITION BLOCK FLOORING

658. Composition block flooring consists essentially of cement, wood, gypsum and calcium carbonate mixed with linseed oil and pigment. The materials are mixed, moulded into blocks under pressure and then cured. The standard size of block is 6 in.$\times$2 in.$\times\frac{5}{8}$ in. and they are laid in a cement mortar on a concrete sub-floor. After laying they are generally grouted with a mix of similar composition to the blocks, faced off and polished. Special blocks are made for coved skirtings and treads, risers and nosing of stairways.

659. The flooring can be laid like wood blocks in a variety of patterns and in various colours. It is hard, but not appreciably more noisy than wood-block

flooring; it is free from dusting and splintering, is moderately warm and not too tiring. When properly maintained the appearance is fair, but all scratches show up readily. When not properly maintained the floor possesses little character and tends to become drab. The wearing qualities are good, it does not stain easily and is easy to clean. The material tends to absorb water, which causes a definite change in linear dimensions. It would therefore be unwise to use this flooring on permanently damp sites or where it may be in contact with water for any length of time. Consequently it would be necessary to incorporate a damp-proof membrane in ground concrete if this flooring is to be used as the final finish.

660. The flooring can be washed with soap and water, but the best appearance is obtained if it is polished at intervals. The manufacturers issue special instructions on this point. For a short time after polishing the floor tends to be slippery, but this may not be serious if polishing is not carried out too frequently.

661. In post-war housing this flooring would be quite suitable for living rooms, halls and bedrooms. It is, however, doubtful whether it would be completely satisfactory in kitchens and bathrooms.

CLAY TILE FLOORING

662. Clay flooring tiles can be made from a number of different clays. The raw material may be first worked into a plastic state, pressed in a mould and then burnt (plastic process) or it may first be dried, ground, pressed after the addition of a small proportion of water and burnt (dry-press process). For the more expensive class of tiles the clays may be refined or pretreated in some special way.

663. Clay tiles are made under various names, *e.g.* quarry tiles of various grades, vitreous or semi-vitreous tiles, mosaic tiles, etc. The terminology is, however, confusing because the terms used do not refer to well-defined and homogeneous classes. For example, the term quarry (French, carré = square) tile is often applied to the cheapest type of clay tile, while at other times it may include vitreous tiles. Generally the vitreous or semi-vitreous tiles comprise the more decorative types of clay flooring tiles, while mosaic is applied to the smaller sizes of the vitreous or semi-vitreous class. Clay tiles are made in various sizes from a 12 in.$\times$12 in.$\times 1\frac{1}{2}$-in. or 2-in. thick quarry tile down to $\frac{1}{2}$-in. squares for mosaic, although probably the most common size for the quarry tile is 6 in.$\times$6 in. $\times \frac{5}{8}$ in. or $\frac{7}{8}$ in., while the 4 in.$\times$4 in.$\times \frac{1}{2}$ in. is the most common for the vitreous tile. Clay tiles are laid on a cement mortar or bitumen bed generally on a concrete or sand base. The joints are kept as thin as possible and are usually grouted with a cement slurry, the surplus of which is then cleaned off with sand or sawdust to avoid staining the tiles with cement.

664. Clay flooring tiles can be obtained in various colours and can be laid in a variety of patterns; the tiles are hard and noisy, but have excellent wearing qualities. The cheapest grade of tiles may sometimes be rather porous and thus tend to collect dirt, while at other times there is a possibility of slight efflorescence appearing after laying, which, however, is not permanent; it disappears after repeated washing. Floors laid with good-quality tiles are easy to clean; they do not scratch readily, so that household cleaning powders can be used without fear of damaging the floor. The tiles are unaffected by water, vegetable or mineral oils and fats. Since generally the good-quality tiles have a smooth dull surface, they become very slippery if polished. Tiled floors are cold and tiring, resembling in these respects concrete floors. Coved skirtings can be produced to match the floor tilings. Floors of this type should be proof against bug infestation.

665. The main precaution necessary in laying is to ensure that the tiles are fully bedded and the joints kept as thin as possible.

666. Clay tiled floors generally need little maintenance beyond the usual washing with soap and water. A coat of linseed oil is sometimes found useful to bring up the colour.

667. In post-war housing tiled floors should prove very satisfactory for kitchens, sculleries, halls and passages. They are too cold for use in main living rooms or bedrooms.

ASPHALT AND CONCRETE TILE FLOORING

668. Asphalt tiles are made from natural asphalt and asphaltic bitumen, with limestone and asbestos fibre as fillers. They are obtainable in a range of colours. These tiles are made in various thicknesses from $\frac{1}{8}$ in. to , in. They can be laid on concrete, being fixed to the base by means of a bitumen adhesive. Coved skirtings can be made to match the tiles.

669. In general properties, maintenance and uses in house construction, they resemble asphalt mastic flooring.

670. Concrete flooring tiles are cast under pressure in steel moulds. They have a normal concrete backing faced with a coloured mix of cement and hard-wearing aggregate. The method of manufacture produces a smooth dense surface and no further polishing is required. They can be obtained in various colours including marbled or mottled effects. The standard sizes are 6 in.×6 in. or 9 in.×9 in.×$\frac{3}{4}$ in. thick. They are laid on a concrete sub-floor like clay tiles in a cement mortar bed, and the same precautions regarding laying apply. In general properties they resemble granolithic flooring.

PLYWOOD FLOORING

671. Plywood can be used successfully as a flooring finish. For this purpose the most common woods are birch, oak and ash. Plywood squares of 9 in., 12 in., or 18 in. square are used to give a parquet effect, while a semi-jointless floor can be obtained by using sheets 5 ft. or 4 ft. square. Material having a top ply less than 3 mm. thick should not be used.

672. Plywood is generally laid on a timber sub-floor and fixed by panel pins. As far as can be ascertained, no successful method of sticking it to any type of sub-floor has been evolved, and this naturally limits the uses. With concrete sub-floors wood batten insets would probably be required at frequent intervals. When laying on concrete ground floors it is essential to introduce a damp course to prevent rising moisture from reaching the plywood.

673. In general properties plywood flooring resembles hardwood and requires similar maintenance. When well laid it has a good appearance and good wearing properties. The situations where it can most suitably be used are living rooms, bedrooms and halls, but it is not recommended for kitchens. In many types of plywood the glues used for bonding are not water-resistant, and because of this such types are unsuitable for bathrooms or other places where conditions are damp. Some types, however, are now being produced with water-resistant glues, and these could be used in any place where wooden strip flooring would be expected to prove satisfactory.

674. The following tables give summaries of the properties of the various floors discussed:

TABLE I. JOINTLESS FLOORS

MATERIAL	APPEARANCE AND SHOWING OF MARKS	NON-CRACKING	EASE OF CLEANING	ANTI-NOISE	NON-SLIP	ANTI-BUG	WARMTH	WEAR RESISTANCE	EASE OF FORMING COVING	SUITABLE SITUATIONS FOR USE
Magnesium oxychloride	F.G. Coloured varieties available	G. Only if carefully laid	F.G.	P.	F.	G.	M.	G.	G.	Living and bedrooms and halls. Damp-proof membrane in ground concrete essential.
Asphalt mastic	M. Coloured varieties available	G.	F.G.	F.	M.	G.	F.	G.	G.	Living and bedrooms, halls and bathrooms. No damp-proof membrane required in base concrete.
Pitch mastic	M.	G.	F.G.	F.	F.	G.	F.	G.	G.	Living and bedrooms, halls, bathrooms, kitchens. No damp-proof membrane required in base concrete.
Cement-bitumen	F.G. Coloured varieties available	G.	F.G.	M.	M.	G.	M.	G.	G.	Living and bedrooms, halls and bathrooms. No damp-proof membrane required in base concrete.
Granolithic	F.	G. Only if carefully laid	F.G.	V.P.	Good unless polished	G.	P.	E.	G.	Kitchens, sculleries, halls and outdoor lavatories.
Terrazzo	G.	G. Only if carefully laid	G.	V.P.	F.	G.	P.	E.	G.	Kitchens, sculleries, halls and outdoor lavatories.
Cement-sawdust	F.G. Coloured varieties available	G. Only if carefully laid	F.G.	M.	F.	?	M.	M.	G.	Living and bedrooms and halls. Damp-proof membrane required in base concrete.
Cement-rubber latex	G. If buffed, otherwise M., coloured varieties available	G.	When buffed G., otherwise F.	M. Depends upon aggregate used	G.	G.	M.	G.	G.	Living and bedrooms, kitchens, bathrooms and halls.
Calcium sulphate	M.	G.	F.G.	V.P.	M.	G.	?	G.?	G.	Living rooms and halls. Damp-proof membrane essential in base concrete of ground floor.

E.=excellent ; G.=good ; F.G.=fairly good ; M.=moderate ; F.=fair ; P.=poor ; V.P.=very poor.

TABLE II. JOINTED FLOORS

MATERIAL	APPEARANCE AND SHOWING OF MARKS	NON-CRACKING	EASE OF CLEANING	ANTI-NOISE	NON-SLIP	ANTI-BUG	WARMTH	WEAR RESISTANCE	EASE OF FORMING COVING	SUITABLE SITUATIONS FOR USE
Linoleum	G. if well maintained. Plain colours tend to show marks.	G.	G.	M.	F.	G.	G.	V.G.	P.	Living and bedrooms, kitchens and halls and possibly bathrooms. Damp-proof membrane essential in base concrete.
Cork carpet	G. if well maintained. Tends to collect dirt otherwise.	G.	F.	V.G.	G.	G.?	V.G.	V.G.	P.	As for linoleum except kitchens.
Cork tiles	As for cork carpet.	G.	F.	E.	E.	G.?	E.	V.G.	Special shapes available.	Living and bedrooms.
Rubber sheet and tiles	G. when well maintained. Plain colours tend to show marks whereas marbled do not.	G.	G.	V.G.	G.	G.	G.	G.	?	Living and bedrooms, bathrooms. Damp-proof membrane in base concrete necessary.
Composition blocks	F.G. if well maintained. Otherwise lose character and become drab.	G.	M.	F.	M.	G.	M.	G.	Special coving available	Living and bedrooms and halls. Damp-proof membrane required in base concrete.
Clay tiles	G. Various colours available.	G.	G.	V.P.	G. unless polished	G.	P.	E.	Special shapes obtainable	Kitchens, sculleries, halls and passages.
Asphalt tiles	F.G. Various colours available.	G.	F.G.	F.	M.	G.	F.	G.	?	Living and bedrooms, halls and bathrooms. No damp-proof membrane required in base concrete.
Concrete tiles	?	G.	G.	V.P.	G.	G.	P.	V.G.	?	Kitchens, sculleries, halls.
Plywood	V.G.	G.	G.	M.	F.	?	V.G.	G.	M.	Living and bedrooms and halls. Damp-proof membrane required in base concrete.

E.=excellent ; V.G.=very good ; G.=good ; F.G.=fairly good ; M.=moderate ; F.=fair ; P.=poor ; V.P.=very poor.

WALL AND CEILING LININGS

675. Sheet materials used as wall or ceiling linings include fibreboard, plasterboard, plywood, asbestos cement sheet, asbestos wallboard, laminated plastics, wood-waste boards, wood-wool building slabs and combinations of these.

676. Restrictions in supply of raw materials or diversion to more essential purposes have for the time being imposed limitations on the quantities of some of these materials available for building use. While some of these restrictions may continue for a time in the post-war period by reason of a need to conserve shipping space or for economic reasons, it may also be assumed that the expansion that has taken place in, for instance, the plastics industry to meet war demands may be redirected to the manufacture of building products, such as laminated plastics. But the production of these and of certain other materials depends on press capacity as well as on supplies of materials. It will be necessary to take account of this in planning for production and utilisation, and this at once raises the question of the sizes of sheet required. At present one factory produces boards in 4-ft. width, another in 5-ft. width, another in 1-metre width and so on, for no apparent reason except that presses of these sizes happen to have been installed. It would make for efficiency if a short list of the sizes preferred by the building industry could be drawn up, in consultation possibly with the aircraft, transport and electrical industries which take their share of some of the products in question. Standardisation could then be achieved gradually as existing plant becomes obsolete.

677. Individually, the various types of sheet material do not offer all the qualities that may be considered desirable for building use. Insulating boards have good thermal qualities but are easily damaged; their appearance is not always acceptable and they are inflammable. Asbestos cement is non-inflammable, but is brittle; it presents some difficulty in decoration and has relatively little insulation value. Laminated plastics are self-decorative but have little insulation value, and when used in the thicknesses necessary to give reasonable rigidity are more expensive than most sheet materials. A closer approximation to the desired properties can be attained by superimposing one material on another. This can be done conveniently in the factory, and there have been certain moves in the direction of manufacture of composite boards aiming to eliminate disadvantages and to combine desirable characteristics in one sheet. Guidance from the building industry on its requirements would assist further development on these lines.

678. The few standard specifications relating to sheet materials intended for building use have been drawn up on an empirical basis, the required properties having been specified from a knowledge of the properties of materials known to give reasonable satisfaction in service. Whether the properties chosen are the best measure of acceptability may be open to question. In this connexion the influence of width of studding on impact resistance and deflection and the connexion, if any, with the transverse strength of the unrestrained board would seem to merit investigation. Similarly, the fire risk associated with the use of the different materials and the extent to which it can be reduced by treating the boards, either in the course of manufacture or afterwards, or by facing with other materials, need inquiry.

679. Except when the board can be used in sizes large enough to cover a whole wall, joint treatment presents difficulties. Filled joints tend to crack because the sheets expand and contract with changes in humidity. The panelled effect of cover strips has come to be associated with cheap and temporary forms of construction, and joints and cover strips can give harbourage to bugs.

FIBREBOARD

680. Fibreboards are made from waste cellulose materials—wood, bagasse, waste paper, and the like—by a process analogous to that used in the manufacture of paper. The bonding of the fibres depends primarily on the lignin and resinous bodies present in the raw material, but some makers supplement these by the addition of sizing agents. There are two types, the homogeneous type and the laminated type.

681. Homogeneous fibreboard is made in two forms, known as insulating board and hardboard respectively. Insulating board is a low-density product (density less than 25 lb./cu. ft., and usually 17–20 lb./cu. ft.) which is prepared simply by drying the sheet as it comes from the machine or mould. The surface texture varies in different makes; some are coarsely fibrous, others comparatively smooth. Some are made with different finishes on the two sides, giving a choice of textures in the one board.

682. Hardboard, a denser product, is made by drying sections cut from the wet, felted mat in a heated press. The board is pressed on a gauze screen, which allows the steam generated to escape, and it usually carries the pattern of this screen on one surface, but sheets having a fair face on both sides are made for use as cubicle partitions. Hardboard is made in three grades, known as medium hardboard (density 30–48 lb./cu. ft.), hardboard and super-hardboard (both of density more than 48 lb./cu. ft.). Super-hardboard is made in the same way as hardboard but is subsequently treated with a drying oil (commonly tung oil) and matured, the object being to increase the water-resistance of the board, which in this form, with suitable paint treatment, is used for covering van bodies and for external walls of temporary or semi-permanent buildings.

683. Laminated fibreboard, also known as laminated pulpboard, laminated wallboard, or simply as wallboard, is also made by a papermaking process, but instead of being made in one homogeneous sheet is built up by combining together several plies or laminations by means of a suitable adhesive, commonly sodium silicate. Laminated fibreboard (of which several well-known examples have been in common use) should not be confused either with laminated plastics, made from synthetic resin-impregnated paper or fabric, which is described in a following section, or with laminated "bitumen board," which is similar to insulating board but is built up of alternate layers of low-density fibreboard and bitumen. One maker at least markets an insulating board which is waterproofed by impregnation with bitumen and is described as "bituminous board." These terms are apt to be confusing.

684. Fibreboards provide a convenient means of covering walls and ceilings. At the same time the low-density type serves to improve the thermal insulation to a considerable degree, $\frac{1}{2}$-in. thickness having an insulation value equivalent to that of 12 in. of brickwork or 10 in. of ballast concrete. Low-density fibreboard in the form of sheets or as specially made acoustic tile is also much used as a sound absorbent for acoustical control in auditoria and offices. It is also used as an underlay for carpets and linoleum. Hardboard can be used as a floor covering, as well as wall and ceiling linings. The fibreboard manufacturers issue detailed drawings and specifications of recommended methods of construction for these various purposes.

685. Insulating board can be supplied in stock sizes or to order in any reasonable length and up to 6 ft. in width. Some firms supply insulating board in special sizes, with specially prepared edges, for use as plastering lath, and also in the form of perforated tiles for purposes of acoustical control. Hardboard can be supplied in stock sizes up to that of the press used, which varies among the different manufacturers, 16 ft. × 5 ft. being the maximum size available at present in this country.

686. As a wall lining material, insulating board has the advantages accruing from its good heat-insulating properties and from its being available in large sizes. Except in the form of perforated tiles its sound-absorbing qualities are more or less impaired by decoration. Insulating board is soft and easily damaged by accidental blows. Its rough surface collects dust and it is liable to show pattern staining and to become discoloured above radiators. Insulating board is inflammable and flame spreads rapidly across its surface; as mentioned in Part I under Fire Hazard, a serious personal hazard to occupants is introduced by its use unless it is suitably treated. Such treatments are described in Part III, paras. 844-8, under Fire Retardant Paints.

687. Hardboards are used in less thicknesses than insulating boards and their insulating qualities are not so good. They are stronger and less susceptible to accidental damage and are sometimes preferred to insulating board below dado level. They do not tend to spread fire as rapidly as insulating board.

GYPSUM PLASTERBOARDS

688. Gypsum plasterboards consist essentially of a core of set plaster of Paris enclosed between and firmly bonded to two sheets of heavy paper. A British standard for plasterboards is in course of preparation.

689. There are two distinct classes of gypsum plasterboard. One class is intended to be used as a base for a plaster finish. This class is subdivided into two types known as "Gypsum Baseboard" and "Gypsum Lath" respectively, the principal difference being in the dimensional sizes and the form of the folded edge.

690. Gypsum Baseboard is generally made in $\frac{3}{8}$ in. thickness only, and in sizes of 3 ft. × 2 ft. 4 in., 2 ft. 6 in., 2 ft. 8 in., 4 ft. 0 in., and 4 ft. 6 in. to suit timber supports at 14 in., 15 in., 16 in., and 18 in. centres. Gypsum Lath is generally made in $\frac{3}{8}$ in. thickness only, and in sizes of 16 in. × 2 ft. 8 in., 3 ft. 6 in., 3 ft. 9 in., 4 ft. 0 in., and 4 ft. 6 in. to suit timber supports at 14 in., 15 in., 16 in., and 18 in. centres. The other class of plasterboard is known as "Gypsum Wallboard," and is a self-finished material to which paint, distemper, wall-paper or other decoration may be applied direct, without any superficial coating of plaster. This class of plasterboard is generally made in thicknesses of $\frac{1}{4}$ in., $\frac{3}{8}$ in., and $\frac{1}{2}$ in., but the $\frac{1}{4}$ in. wallboard is generally recommended as being suitable for ceilings only. The usual widths are 2 ft. 0 in., 3 ft. 0 in., and 4 ft. 0 in. to suit timber supports at 18 in. and 16 in. centres, but an extra width of 3 ft. 6 in. is supplied in Scotland only by some manufacturers. The standard lengths are 6 ft., 7 ft., 8 ft., 8 ft. 6 in., 9 ft., 10 ft., 11 ft., and 12 ft. A form of gypsum plasterboard $\frac{3}{4}$ in. thick known as "Gypsum Plank" is also made which has semi-structural uses.

691. In addition, there are small differences between different makes of plasterboard, as, for example, in the incorporation of small quantities of sawdust or of foaming agent in the plaster or in the variation in manufacturing detail in the method of procuring good adhesion between paper and plaster.

692. The general properties of the two types are similar. In comparison with wood-fibre insulating board, plasterboards are somewhat heavier and have less insulating value. Being composed of incombustible materials, they do not give rise to risk of spread of flame over their surfaces. The dimensional changes with changes in moisture content are considerably smaller than for wood-fibre products. Plasterboards are sensitive to moisture, being much weaker when wet and being ultimately disintegrated by prolonged exposure to damp or to repeated cycles of wetting and drying. They should not therefore be used in damp situations and should be protected against rain during transport and storage. One or two cycles of wetting and drying, such as may take place while plastering, will not cause deterioration.

693. The normal method of fixing is by nailing to timber supports, using broad-

headed galvanised plasterer's nails, along the edges of the boards, at frequent intervals, breaking joints for boards to be subsequently plastered. The studding should be arranged to give support at the edge. The practice which has sometimes been adopted of leaving a joint unsupported is to be deprecated as leading almost invariably to cracking of the plaster finish at the joint. Recently, alternative methods of fixing on concrete or steel members, such as that using light metal sections to support the edges of the boards, and wiring or strapping the metal to the main members, have been developed as a means of timber economy.

694. The problem of concealing the joints of boards without plaster finishes is much the same as that for other wallboards and is discussed later. Plastering on plasterboards is also dealt with in a later section.

ASBESTOS CEMENT SHEET

695. Asbestos cement sheet is made from asbestos fibre and Portland cement by a process somewhat analogous to that used in making paper. It is supplied in sizes up to 8 ft.×4 ft. in thicknesses of $\frac{5}{32}$ in., $\frac{3}{16}$ in. and $\frac{1}{4}$ in., 8-ft.×4-ft. sheets are also supplied in $\frac{3}{16}$-in. and $\frac{3}{8}$-in. thickness. The makers recommend $\frac{3}{16}$-in. or $\frac{1}{4}$-in. sheet for internal wall linings. Flexible sheets for use on curved surfaces are made in $\frac{1}{8}$-in. thickness. Decorative sheets with embossed designs, and others in a large variety of glazed finishes, are also supplied for internal use.

696. Asbestos cement sheet is non-inflammable and incombustible, but is liable to shatter if strongly heated. Though strong it is brittle and easily damaged by impact, and because of its alkaline character requires special paints for decoration (see section on Painting). Dimensional changes with changes in moisture content are considerably greater than with plasterboard.

697. Composite boards of asbestos cement sheet and plywood are produced commercially, the use of which would tend to eliminate some of these disadvantages.

ASBESTOS WALLBOARD AND ASBESTOS WOOD

698. These materials, also based on asbestos fibre, are softer than asbestos cement and are primarily designed for interior work. It is possible to nail both materials without serious risk of their cracking. They are supplied in the following sizes:

Asbestos wallboard: 8 ft., 10 ft. or 12 ft. long by 4 ft. wide by $\frac{3}{16}$ in. or $\frac{1}{4}$ in. thick. 8-ft. by 4-ft. boards are also supplied in $\frac{1}{8}$-in. thickness.

Asbestos wood: 8 ft. by 4 ft. by $\frac{1}{2}$ in., $\frac{3}{8}$ in., $\frac{1}{4}$ in. or $\frac{3}{16}$ in.

PLYWOOD

699. Plywood consists of three or more veneers of wood bonded together with glue in such a way that the grain of the alternate veneers lies in different directions, usually in directions at right angles to one another. Manufacture of plywood is the least wasteful method of utilizing timber. Plywood has practically displaced use of matched boards for wall linings.

700. The development of synthetic glues, which are highly resistant to water and are immune from attack by micro-organisms, has greatly extended the field of application for plywood, but for interior use in building the older animal or casein types of glue are generally quite satisfactory unless the situation is damp.

701. Plywood is made in a range of thickness up to 2 in. and in sizes up to 8 ft. by 28 ft., though the general run of stocks is about 5 ft.×4 ft. or 5 ft.×5 ft. Sheets can be scarfed to produce units of any size required, so that whole walls can be covered in one piece.

702. Plywood can be stained or painted or it can be faced with decorative veneer, with plastic sheet or with metal.

703. Manufacture of plywood from imported veneer or from home-grown timber has been increased for war purposes and use might be made of these manufacturing facilities in the post-war period.

LAMINATED PLASTICS SHEET

704. Laminated plastics sheet, which is to be distinguished from laminated fibreboard, is made by impregnating paper or fabric with a synthetic resin and bonding together the number of sheets necessary to make a board of any desired thickness by the application of heat and pressure.

705. The sheets are made in a wide range of colours, in glossy, satin-matt and matt finishes. A printed paper or fabric can be used as the facing sheet; the design then becomes part of the sheet and is as permanent as the sheet itself. The sheet can also be faced with decorative wood veneer or with metal; in fact, wood veneer, paper, fabric or metal can be combined in the process of manufacture in any arrangement desired. Sheets intended for surfacing counters and table tops are commonly made with an underlying sheet of metal to provide a heat-conducting layer and confer immunity from cigarette burns. Different makers use presses of different sizes, 8 ft.×4 ft. being the largest so far available in this country.

706. A similar type of plastics sheet is made by a "premix" process in which, instead of impregnating paper with resin, the resin is added to a rag pulp. The pulp is then run off on a papermaking machine and after drying is bonded under heat and pressure to make a board. Boards of this type have not yet been produced in quantity, principally because the pressing facilities have not been available.

707. Laminated plastics are strong and are self-decorative. They are resistant to wear and are easily kept clean. The surface can be marred by scratching before or after erection and is not easily restored unless a matt finish is used. The boards can be nailed, but only after drilling. The fire risk is probably less than that associated with fibreboard or plywood. Though relatively expensive, the hygienic qualities and good appearance of laminated plastics make them particularly attractive as linings for bathrooms and kitchens. Advantage may be taken of these qualities and at less cost by using the plastics sheet as a thin facing over hardboard. Materials of this kind, known as "fibre tile boards," have been made and used in the United States. Laminated plastics veneered on hardwood or plywood are also available in this country.

WOOD-WASTE RESIN BOARD

708. Manufacture of sheet materials from sawdust, wood chips or other industrial waste products, such as asbestos-waste or flax residues and synthetic resins, is a war-time development which has been handicapped by limitation in the supplies of synthetic resins and in press capacity. The method of manufacture consists in mixing the sawdust or other material with the requisite quantity of a binding agent, for which purpose urea-formaldehyde, phenolic or cresylic resins and cellulose acetate have been used. The mixture is moulded into sheets under suitable conditions of temperature and pressure.

709. The properties of the board can be varied by varying the proportion of the binding agent and the making pressure. For maximum utility the board needs to have adequate strength but yet be capable of being sawn and nailed without difficulty. Some very promising materials have been produced and further development may be expected when supplies of resins are more freely available. The appearance of the boards depends on the character of the materials used. Some may be considered to be self-decorative, and they can be faced with decorative veneer or with a laminated plastics sheet in the process of manufacture.

(*Note.* During the war, building slabs composed essentially of sawdust or wood chips and cement have been used for temporary buildings of the hutment type. It is indicated in a later section (Light-weight Concrete Aggregates and Light-weight Concretes, p. 120) that material of this type requires careful design treatment in order to accommodate its particular physical properties, which are of a different type from other cement products. This need for care in design applies both to the actual shape of the slab and to its method of use. As an example of the limitations in the use of this type of material, which are due to its characteristics, the plastering or rendering of a partition composed of slabs of this type is not likely to be successful because of the high moisture movement of the sawdust cement backing; a finish of sheet material is sounder practice.)

WOOD-WOOL BUILDING SLABS

710. Wood-wool building slabs consist essentially of wood-wool (specially prepared long wood shavings) and a mineral cementing agent, pressed together mechanically and matured. Their quality is subject to a Specification (*British Standard* 1105–1943), in which three grades, "normal quality," "special quality" and "reinforced slabs," are described. For lining material the "normal quality" is generally used, but the stronger "special quality" slab may be required if used as permanent shuttering in poured concrete work or under other special conditions.

711. Dimensions of the British Standard slabs are 6 ft. by 2 ft., in 1-in., 1½-in., 2-in. and 3-in. thicknesses; ½-in. and ⅝-in. thick slabs are also made. The thicknesses up to 1½ in. are normally used for interior linings, but the thicker slabs may be used for example for free standing partitions. Suitable centres for supports on walls or ceilings are indicated in an Appendix to the Specification.

712. The appearance and texture of these slabs usually necessitates plastering. They are sometimes used with only a spray paint finish for acoustic linings, but such a finish is unsuitable in low-cost housing.

713. Wood-wool slabs have favourable characteristics in respect of non-inflammability and fire resistance. Their thermal conductivity is low and in the thicknesses used they give good thermal insulation. Their strength is low compared with most other lining materials, but their use in greater thickness compensates in some degree for this.

OTHER SHEET MATERIALS

714. In addition to the various types of wall linings described, mention may also be made of certain newer materials which can be made in sheet form for use, not as surfacing materials, but as insulating linings. One material of this kind, built up of thin sheets of cellulose acetate in a cellular form, is already on the market. It is extremely light in weight, has good thermal properties, and is relatively unaffected by moisture. Cellulose acetate, polystyrene and urea resins can be made into light-weight blocks and sheets. These have not yet become generally available, but doubtless will be when supplies of the raw materials are less restricted.

COMPOSITE BOARDS

715. Some firms supply composite boards combining two types of sheet material A board of this kind made by the asbestos cement manufacturers is supplied either as with ⅛-in. asbestos wood between two sheets of ½-in. plywood, or ¼-in. asbestos wood with ¾-in. plywood on one side. Some plasterboard manufacturers in the U.S.A. make a plasterboard with a wood veneer face, but none is at present made in this country. One of the fibreboard manufacturers in the United States supplies

a composite board consisting of a 1-in. fibreboard faced on both sides with asbestos cement sheet, but again this material has not yet been produced or marketed in this country as far as is known. Reference has already been made to the production in the United States of insulating fibreboard faced with laminated plastics sheet and sold under the name of "fibre-tile board." Laminated plastics and metal are customarily combined to make "cigarette-proof" table tops. Metal-faced plywood is in regular production.

716. Combinations of this kind can be chosen to unite the advantages of different materials and to minimise or eliminate their disadvantages. Examples are almost too obvious to be mentioned. An insulating board faced with laminated plastics sheet combines thermal insulating value with a self-decorative, hygienic surface. The board is stronger and stiffer and is less liable to damage in use, and at the same time the danger associated with the rapid spread of flame on the fibreboard is eliminated. By using an expanded plastic for the core, quite thick and correspondingly stiff sheets can be made which are extremely light in weight. Metal-faced plywood provides the appearance and wear resistance of metal without excessive weight.

717. By using cold-setting glues chosen to suit the materials any required combination of sheet materials can be erected on the site. But the technique of making resin-bonded plywood lends itself to the manufacture of composite boards of all kinds. Given sufficient encouragement from the building industry, and guidance as to the properties required in the products, there would seem to be every prospect of useful development in this direction.

FIXING

718. Linings may be fixed to walls and ceilings:

a. By nailing, screwing or gluing to battens on solid walls, or to wood strips embedded in the mortar joints, to timber stud framing, or to the ceiling joists.

b. By direct fixing to solid walls or ceilings, using suitable adhesives.

c. By insertion in prepared slots in timber-framing or in beadings in metal or plastics, suitably designed to hold the edges of the board.

d. By using them as permanent shuttering in concrete construction.

719. In fixing to battens or studs all the edges of the sheets need to be supported. The makers issue detailed instructions, including recommended spacing for studs and battens, but the recommendations seem to be determined as much by the necessity for the spacing to fit the width and length of the sheet as by any special consideration of its strength and flexibility. Among the materials dealt with, laminated plastics and asbestos cement sheet need to be drilled. Some wood-waste boards can be nailed without difficulty; others need drilling; the fixing of plasterboard has been mentioned earlier.

720. It is reported that large prefabricated units are being made in the United States by gluing the framework and facing sheets all together in one operation. Gluing *in situ* to a framework would be a feasible operation using cold-setting synthetic glues, but experience with such glues has been somewhat limited; their permanence may need further inquiry. Sticking directly to solid walls or ceilings, though referred to in the trade literature on fibreboard as a method of fixing, would seem to need special preparation to ensure a uniform level in the finished surface, though the method has the advantage that the board is supported over the major part of its area.

721. To allow for expansion and contraction, sheet materials are fixed with a small gap between adjacent sheets. They should not be forced into position. With fibreboard a gap of $\frac{1}{8}$ in. is usually recommended, and the makers' instructions provide for conditioning the boards by leaving them exposed to the air for 24 hours before fixing.

722. Insulating boards and hardboards and wood-wool building slabs are used as permanent shuttering. They are lightly tacked in position inside the forms so that on removing the forms they remain permanently bonded to the concrete. The amount of formwork required varies with the thickness and strength of the sheets or slabs used. Insulating board used in this way improves the thermal insulation of the wall and minimises condensation. The board can be used as a base for plastering. When hardboard is used the face is carefully protected by lining the forms with building paper and the surface is then ready for decoration. There have been suggestions that laminated plastics might be bonded to concrete in the same way, but there is reason to suppose that the bond is not good without the assistance of a mechanical key. This difficulty might perhaps be overcome by using laminated plastics backed with fibreboard. Use as permanent shuttering differs from the use of hardboard or resin-bonded plywood to line the forms in order to leave a good surface finish on the concrete. The boards are then oiled to prevent adhesion and are removed when the shuttering is struck.

JOINT TREATMENT

723. Fibreboards and plywood are obtainable in large sizes so that, although the practice has not often been adopted, it is possible to line rooms of moderate size with these materials without breaking the surface with vertical joints. Otherwise the joints can be finished with cover strips of any suitable material to give a panelled effect, or they can be covered with strips of fabric or thick paper, specially supplied for the purpose, which, when decorated, are comparatively inconspicuous. Another method, applicable to fibreboards, is to secret-nail the boards and to bevel the edges of the sheet to make a decorative feature of the joint itself; the makers sell or loan tools for this purpose. Laminated plastics sheet could be supplied with the edges specially moulded to eliminate the need for cover strips, and it is expected that the makers will be giving attention to this point.

724. Another method is to fill the joint with plaster or mastic, but such joints are liable to crack. When the board is to be plastered the joint is reinforced with wire gauze or fabric.

DECORATION

725. Laminated plastics can be supplied in almost any colour and surface finish required. They do not require decoration and can be readily cleaned with a damp cloth; if in the course of time they become shabby where they are exposed to rough usage, they can be painted, using paints recommended by the makers. Plywood faced with decorative veneers does not need painting, and some of the materials made from wood waste may be considered decorative in themselves. Other sheet materials normally need decoration. This subject is dealt with in the general section on painting.

SHEET MATERIALS AS PLASTER BASE

726. Three types of material, fibreboard (insulating board), plasterboard and wood-wool building slabs, are used as a base for plastering.

727. PLASTERING ON FIBREBOARD. Some of the firms supply fibreboard as "plastering lath" in special sizes (48 in.× 18 in. or 36 in.× 18 in.) with the edges prepared to give an overlap at the joints, and also, in some makes, with bevelled edges. Gypsum plasters are used, either in a single coat of neat plaster $\frac{1}{8}$ in. thick, or in two-coat work, using a 2 : 1 sand-gypsum plaster mix for the undercoat.

Unless plastering lath is used, the joints need to be reinforced with wire gauze tacked in position, or with hessian, linen or cotton scrim either tacked or simply laid along the joint and pressed into the plaster with a trowel. This helps to avoid cracks developing in the plaster over the joints, but even so it may be difficult to prevent a certain amount of cracking. The adhesion between the fibreboard and the plaster is good and usually exceeds the strength of the board. Fibreboard can also be faced with cement rendering reinforced with chicken wire.

728. PLASTERING ON GYPSUM PLASTERBOARD. Gypsum plasterboard may be plastered either by the application of a single neat coat of plaster or by the adoption of the more normal technique of two-coat plastering. The former has the disadvantage that if the background to which the boards are fixed is uneven it may not be possible to bring the work to a level finish. Cracks are also liable to develop over the joints between the boards. On the other hand, as the boards afford no mechanical key as does lathing, the sanded undercoat of two-coat work must be of a type which provides adequate adhesion to the boards.

729. A retarded hemihydrate gypsum plaster is usually recommended for this type of work and there is some advantage, for single-coat work, in using a "low-expansion" variety to avoid buckling of the board. Finishing plasters modified to reduce the setting expansion are available for this purpose. Addition of lime to the plaster in contact with the board adversely affects the adhesion and is not recommended but, in the case of two-coat work using a sanded undercoat free from lime, a finishing coat containing lime may be used.

730. For single-coat work the most common method is first to fill all joints with neat finishing plaster, covering them with a thin coat of plaster about 4 in. wide. A 4 in. band of hessian or cotton scrim or a 3 in. strip of light gauge expanded metal is then laid along the joints and pressed in with the trowel. When the joint is set and hard, a coat of neat finishing plaster is applied to a thickness of the order of $\frac{3}{16}$ in. Methods and mix proportions for two-coat work are given in the various plaster manufacturers' booklets, and in such cases it is advisable to follow the particular recommendations given.

731. PLASTERING ON WOOD-WOOL BUILDING SLABS. The open texture of wood-wool building slabs gives an excellent key for plastering and they present no special difficulties. Joints are usually covered with jute scrim. Two- or three-coat work is necessary owing to the rough surface of the slabs. Any type of plaster can be applied.

THE PROPERTIES OF WALL-LINING MATERIALS

732. There is difficulty in collecting a summary of the properties of wall-lining materials because of the variety of different makes, and because the data, where available, have not all been determined under the same test conditions. The attached table is included with the reservation that it does not purport to convey more than a generalised comparison between the various types of material or, necessarily, to cover the whole range of varieties in any one material.

733. STANDARD SPECIFICATIONS. There are only three British Standards relating specifically to sheet materials for building use, namely:

B.S. 690–1940: *Asbestos Cement Slates and Unreinforced Flat Sheets and Corrugated Sheets.*

B.S. 1105–1943: *Wood-wool Building Slab.*

B.S. 1142–1943: *Fibre Building Board for General Building Purposes.*

There are, however, specifications for certain other sheet materials dealt with in the preceding paragraphs, or for materials used in their manufacture, which, though not primarily concerned with building uses, may be considered to be relevant, and are accordingly listed on p. 119.

Properties of Wall-lining Materials

Material	Transverse strength: Modulus of rupture lb./sq. in. (dry)	Transverse strength: Wet/dry ratio (24 hrs. in water)	Density lb./cu. ft.	Thermal conductivity B.Th.U./sq. ft./hr./°F./in.	Moisture expansion per cent. (24 hrs. in water [1])	Water absorption weight per cent. wt. of dry product (24 hrs.)
Insulating board	250–400	0·2–0·4	16–25	0·3–0·4	0·4–0·5	30–100
Medium hardboard	1500–2000	0·7	30–48	0·5–0·7	0·3	15–30
Hardboard	3000–4000	0·5–0·7	50–65	0·5–0·7	0·2–0·3	15–120
Super hardboard	4000–5000	—	50–65	0·5–0·7	—	15–20
Laminated fibreboard	1000–2000	0·0	40–45	0·53	—	130
Plywood	2000–20000	0·5–0·8	35–45	1·0	0·2–0·5	25–35
Plasterboard	700–2000	0·2	50–70	1·1–1·4	Low	40–50
Asbestos cement sheet	2500–5000	0·8	110–120	1·5–1·9	0·2–0·25	20–28
Asbestos wallboard	2200–2700	0·7–0·9	74–77	—	—	53
Asbestos wood	3000–3800	0·5	72–84	—	—	52
Laminated plastics	15000–30000	0·6–0·8	80–85	1·4–2·3	0·1–0·5	0·2–2·0
Wood-waste board	800–7000	0·3–0·9	35–70	—	0·5–2·0	10–100
Wood-wool building slab	50–250	—	25–50	0·6–0·7	0·2–0·3	High porosity

[1] Measurements on specimens previously conditioned to equilibrium in an atmosphere maintained at 65 per cent. relative humidity at 20° C.

BRITISH STANDARDS

316–1929: *Synthetic Resin Varnish Paper Boards and Tubes for General Electrical Purposes.*

474–1932: *Synthetic Resins (Phenol Formaldehyde) for Manufacture of Boards, Tubes, and Cylinders.*

547–1934: *Synthetic Resin Bonded Paper Sheets (Grade 1) for Electrical Purposes.* (Under revision.)

231–1936: *Pressboard for Electrical Purposes.*

972–1941: *Synthetic Resin Bonded Fabric Sheet for Electrical and Mechanical Purposes.*

6*V*3: *High Strength Plywood for Aircraft.*

4*V*2: *Casein Glue for Aircraft Purposes.*

MINISTRY OF AIRCRAFT PRODUCTION: MATERIAL SPECIFICATIONS, D.T.D. SERIES

335*A*: *Synthetic Resin Cement (Non-gap-filling).*

484: *Synthetic Resin Cement (Gap-filling).*

427: *Plywood for Lightly-stressed Parts of Aircraft.*

LIGHT-WEIGHT CONCRETE AGGREGATES AND LIGHT-WEIGHT CONCRETES

734. Light-weight concrete has been used for house building chiefly in walls and floors. The present note describes briefly the materials which are used in making light-weight concrete, the properties of the products, and some of the ways in which they are used.

TYPES OF LIGHT-WEIGHT CONCRETE

735. As the name implies, light-weight concretes are those which are lighter in weight than normal concretes, such as those made with sand and gravel or crushed stone aggregates. The latter may weigh 140–150 lb./cu. ft. and any concrete weighing less than, say, 120 lb./cu. ft. may be classified as a light-weight concrete. However, light-weight concretes used in house construction usually weigh less than 90 lb./cu. ft. and it is this type which is considered primarily in this note, brief reference only being made to concretes within the weight range 90–120 lb./cu. ft. The lowest weight which is generally considered is in the range 45–50 lb./cu. ft., although concretes lighter than this can be obtained and are occasionally used for special purposes.

736. Concretes within the weight range of 45–90 lb./cu. ft., broadly speaking, are made either by using light-weight aggregates or by causing gas or air bubbles to form in a cement slurry so that the cement sets to a cellular mass. It is quite possible to combine the two methods to make a product in which the cement matrix is cellular and the aggregate is a light-weight type. So far as is known, however, this method has only been used, and to a limited extent, in the United States. In this country, the main experience has been with light-weight aggregates only, though some use has been made of the cellular concrete.

737. CONCRETE MADE WITH LIGHT-WEIGHT AGGREGATES. *Types of Light-weight Aggregate.* Light-weight aggregates can be classified in three main groups—*i.e.* naturally occurring aggregates, aggregates arising as by-products, and specially made or processed aggregates.

738. The naturally occurring aggregates are nearly all of volcanic origin. *Pumice* is the most widely used of the group and was imported into this country before the war. Impurities present in it may include clay or shale which are unfavourable

to the production of good concrete; these impurities can, however, be removed by washing; the resulting washed pumice being usually regarded as being one of the best of the light-weight aggregates.

739. By-product aggregates include furnace clinker, crushed brick, blast-furnace slag, and sawdust. Of these, the *crushed brick* and the *blast-furnace slag* aggregates when used in concrete produce mixes which are heavier than the 90 lb./cu. ft. mentioned earlier and are therefore not considered further. Concrete containing *sawdust* can be made within the weight limits suggested, but the other properties of this concrete are of a different order from other light-weight concretes and, except for nailing blocks, the material requires to be used in a different way, and never as a direct alternative for ordinary light-weight concrete. The remaining member of the group, furnace clinker, has been widely used in the past, particularly for partition slabs. Breeze blocks are usually made from these furnace residues rather than from coke breeze proper. The main advantages of this aggregate are that sources are well distributed over the country and it is cheap. Against this, the grading of material as produced may not be the most suitable—there is usually more fine material in the aggregate as a whole than is required—and even with a suitable grading the aggregate is rather heavy and the resulting concrete is at the heavier end of the range. More important than any of these, however, is the presence of incompletely burnt fragments, which may lead to unsoundness in the concrete by producing an expansion; not all coals show this effect. In practice the simplest method of detecting whether or not the clinker is unsound is by a pat test on the clinker as described in *British Standard* 834–1939.[1]

740. Clinker aggregates therefore require careful control if troubles are to be avoided; in particular, care should be taken to see that all deliveries are sound as shown by the pat test. One other defect also exists, namely that clinker can be intrinsically corrosive to embedded steel.

741. Processed aggregates include expanded slags, clays or shales, and slates. *Foamed slag* is of this type and is made by treatment of molten blast-furnace slag. As supplied to the user, the foamed slag is crushed and graded into fine ($\frac{1}{8}$ in. down) and coarse ($\frac{1}{2}$ in.–$\frac{1}{8}$ in.) grades. The aggregate is made in this country and there are ample quantities of raw material; the availability of the final product is, however, dependent on the capacity of the pretreatment plants for expanding the slag, so that the available quantities at present are considerably less than those of clinker. There is a British Standard for the material for use as a concrete aggregate (*British Standard* 877–1939). *Expanded clay or shale* is made by firing a suitable clay or shale to partial fusion in a manner which produces an expanded product. There are a number of plants making material of this type in the United States, and it has also been made in this country, but the output at present is relatively small. *Expanded slate* can be made in the same way as the expanded clays, but is not produced here at present because of economic factors.

742. All three of these processed materials produce concretes which, in suitable mixes, have properties closely approaching those of pumice concrete. Further, by adjusting the conditions of the concrete making, a fairly wide range can be obtained in weight, strength, and insulation value. They do not have the defects associated with clinker concretes.

743. *Wood-wool* can also be considered as a processed fibrous aggregate for concrete, but has a different method of application and is not interchangeable with the other aggregates.

744. PROPERTIES OF THE CONCRETES. This class of material does not have to meet the same type of requirements as ordinary concrete. The desired pro-

[1] A British Standard for clinker for a concrete aggregate is in course of preparation and will be more appropriate to use when available. This will also include limits for the combustible content of clinker according to the purpose for which it is to be used.

perties, in addition to lightness in weight, are chiefly that they should have low thermal conductivity, be able to take and hold nails, be relatively easily cut and provide a surface giving a good key for plastering. These properties can only be obtained with the known materials at the expense of a considerable reduction in strength, and of an increase in permeability compared with ordinary concrete. As with other concrete products, light-weight concretes shrink during the initial drying and then have a reversible expansion and contraction on subsequent wetting and drying, the latter movements being of smaller magnitude than the first. With light-weight concretes the movements may take place more quickly than with a dense concrete, because their more porous texture allows them to dry and re-wet more quickly. The order of magnitude of the movements of light-weight concrete is in many cases about the same as, or not very much greater than, that of ordinary concrete, but it may attain considerably higher values in certain light-weight concretes. As a general rule, it is better to avoid the latter type for ordinary building work; they are excluded, for example, in the British Standards for partition slabs (*British Standard* 492–1933) and concrete blocks (*British Standard* 834–1939). Other precautions to avoid troubles from these movements are mentioned later.

745. The order of properties obtained with pumice, clinker and foamed slag light-weight concretes in comparison with gravel concrete is given in the table following:

MATERIAL	DENSITY lb./cu. ft.	COMPRESSIVE STRENGTH lb./sq. in.	TRANSVERSE STRENGTH lb./sq. in.	DRYING SHRINKAGE PER CENT.	THERMAL CONDUCTIVITY B.TH.U.'S, ETC.
Pumice concrete					
1 : 6	45–70	200–550	100–150	0·04–0·08	1·4 (48 lb./cu. ft.)
1 : 10	—	—	—	—	1·1 (41 lb./cu. ft.)
Clinker concrete					
1 : 6	50–105	150–450	75–250	0·03–0·20	2·8 (105 lb./cu. ft.)
1 : 10	—	—	—	—	2·3 (95 lb./cu. ft.)
Foamed slag concrete 1 : 6	80–95	300–1500	200–300	0·03–0·05	1·5–2·2 (70–80 lb./cu. ft.)
1 : 12	65–95				
Ballast concrete 1 : 2 : 4	About 140–150	3000–5000	—	0·03–0·04	7·0 (150 lb./cu. ft.)

746. CELLULAR CONCRETES. Hydrogen gas bubbles can be generated in a mix containing lime or cement by incorporating finely divided aluminium or zinc powder in the mix. The cellular structure produced in this way is retained after the cement has set and a light-weight product obtained thereby. A similar structure is obtained when a foaming agent is used instead of the metal powder, the mix being whipped up in a special mixer to a fine foam. The properties of the product can be varied to some extent according to the amount of air or gas which is introduced and the proportion of sand used. The normal range is roughly:

Density	37–60 lb./cu. ft.
Compressive Strength	200–500 lb./sq. in.
Transverse Strength	100–240 „ „
Thermal Conductivity	1·0–2·0 B.Th.U.'s, etc.
Moisture Movement	0·05–0·18 per cent.

The moisture movement tends to be rather high, but there are indications that products which are steam-cured are better in this respect than those which are air-cured in the normal way.

747. METHODS OF USE OF LIGHT-WEIGHT CONCRETES. Light-weight concretes can be used both in the precast and cast *in situ* forms. In the past, much the greater quantity has been as precast blocks, and for wall construction this form has an advantage in that the initial drying shrinkage of the material takes place during the maturing period in the manufacturer's yard, rather than in the structure; any risk of shrinkage cracking is therefore reduced. *In situ* light-weight concrete has been used most particularly in floor and roof construction, for the insulation of pipes in the ground, and the like. Both forms can be used for the protection of structural steelwork against fire hazards, and light-weight concretes as a class are an important asset in fire protection, although their use for this purpose may be less significant in housing than in larger structures.

748. WALL CONSTRUCTION. The best known application of light-weight concrete is in the form of partition slabs for internal walls, a breeze block partition being in common use in many pre-war house-building programmes; the tendency has been to use thin partitions. These are non-load-bearing, but require to be tied in adequately to the frame or structural walls.

749. There have been difficulties associated with light-weight concrete block partitions, arising from cracking caused by moisture movement, by pinching of the partition through distortion of the structural frame, by thermal expansion of a flat roof to which the top of the partition may be tied, or to unsoundness of the clinker aggregate. The incidence of these troubles, however, depends on the size of the structure and, on the whole, except for clinker unsoundness, they are much less likely to occur in relatively small buildings of the domestic type. The precaution should always be taken of using only partition slabs which conform with *British Standard* 492–1933, which, amongst other requirements, ensures that the moisture movement shall be suitably low in value, and, for clinker blocks, ensures the use of a sound clinker. It may be noted, however, that pinching of the partition, or cracking through thermal movement of the roof slab, are features which can occur with partitions other than light-weight concrete.

750. Light-weight concrete has, on the whole, some advantages over many of the other partition materials in respect of fixings to the partition and of cutting for plumbing, electrical and gas services. The lighter fixings, skirtings, picture rails and even door frames, etc., can usually be nailed direct into the material and, in fact, nailing blocks of light-weight concrete are frequently used in brick walls to take fittings of this type, but more careful treatment may be required for fixing heavier fitments, such as lavatory basins.

751. External walls can also be built in light-weight concrete blocks. In this case it is desirable that the blocks should comply with *British Standard* 834–1939 for precast concrete blocks for walls. Apart from offering a direct alternative to brickwork, the heat transmission through a given thickness is less than either brickwork or normal concrete. External walls of light-weight concrete should, however, be protected with an external rendering, preferably of the cement-lime type. If properly applied, this removes the risk of direct rain penetration and, in keeping the blocks dry, permits of the maximum efficiency being attained in thermal insulation. In any event, the blocks have hardly a sufficiently decorative texture to be left untreated. The risk of cracking through moisture movements is rather greater under external walling conditions than in interiors and, therefore, requires more thought in handling and in design. The choice of blocks conforming to the British Standard is a first step; as a second, it is a wise precaution to take all reasonable steps to protect the slabs during transport and on the site from soaking by rain before they are built into the wall. A cement-lime mortar for bedding, being weaker than a cement mortar, allows for distribution of the shrinkage stresses in the mortar and reduces the risk of a continuous shrinkage crack in the wall

and should, preferably, be used; a cement mortar is in any event unnecessarily strong for this type of material. Lastly, it is an advantage to avoid having large areas of rendering, without a break which can act as a shrinkage joint. In pier-and-panel forms of construction it is not usually difficult to arrange for this joint at the post, but there is more difficulty in ordinary load-bearing wall designs. The importance of the point lies in preventing rain penetration into the wall, and not in any question of stability. It is probably the main point of difference between normal brickwork construction and light-weight concrete block construction in which the latter is at a disadvantage.

752 FLOOR CONSTRUCTION. When light-weight concrete is used as part of the structural floor, the material is most often cast *in situ*. As somewhat greater strength is frequently required than is necessary in the walling blocks, the mixes may have to be richer in cement, while, for better workability, the proportion of fine to coarse aggregate may often, with advantage, be greater than that in normal concrete, *e.g.* 1 : 3 : 3 or 1 : 3 : 4 by volume, rather than 1 : 2 : 4. At the same time in placing the mix, it must be remembered that maximum compaction does not ally itself with lightness in weight. Excessive compaction may also have the effect of crushing the aggregates, which are more friable than heavy aggregates. When an open paddle type of mixer is used, it has been found better to mix the aggregate and water first, then to add the cement, rather than first mixing the dry constituents followed by the water. It is not known whether this applies also to the drum type of mixer. The use of an excess of water in an attempt to give greater workability is to be avoided as giving rise to the possibility of segregation in placing the concrete.

753. REINFORCEMENT. One question frequently raised is whether there is any danger of corrosion of steel reinforcement embedded in light-weight concrete. On this there are two factors to be considered. In the first place light-weight concretes, being more permeable, do not have the same protective effect characteristic of dense concrete in preventing access of air and moisture to the steel. Therefore, when the reinforced light-weight concrete is used on external surfaces, it is desirable to have a greater depth of cover and to have the additional protection of a rendering or surface screed. Secondly, there is the question whether the constituents of the light-weight concrete have themselves any intrinsically corrosive effect. This obviously requires individual consideration of the materials. It is now well known that clinker aggregates can have an intrinsically corrosive action and should therefore not be used in proximity to steel. On the other hand, the other common materials (pumice, foamed slag, and the cellular concretes) have no such intrinsically corrosive effect. The question does not yet appear to have arisen with expanded clays or shales and may require consideration with different samples, depending on whether or not they contain corrosive salts. The basic material itself is not corrosive.

754. FURTHER INFORMATION. A considerable body of information on light-weight concretes and light-weight aggregates from various sources has been given in technical journals. Without giving a bibliography of these, the following may be selected as containing data which will supplement and amplify the information given above.

Light-weight Concrete Aggregates (F. M. Lea, Building Research Bulletin No. 15, 1936. H.M. Stationery Office).[1]

Light-weight Aggregates for Concrete (Forrest T. Moyer, U.S. Bureau of Mines, Information Circular I.C. 7195, 1942). (Reproduced also in the journal *Cement, Lime and Gravel*, 1942, August (p. 54), September (p. 77), and October (p. 105).)

[1] This publication is, unfortunately, out of print at present but may be available for examination through libraries.

Properties of Breeze and Clinker Aggregates and Methods of Testing their Soundness (F. M. Lea, Building Research Bulletin No. 5, 1928. H.M. Stationery Office).

Corrosion of Steel by Breeze and Clinker Concretes (F. L. Brady, Building Research Special Report No. 15. H.M. Stationery Office).

Foamed Blast-furnace Slag (T. W. Parker, Iron and Steel Institute Special Report No. 19, 1937. Iron and Steel Institute).

Principles of Modern Building, vol. 1 (R. Fitzmaurice. H.M. Stationery Office (particularly pp 173-202)).[1]

EXTERNAL RENDERINGS

755. External renderings are usually chosen primarily for their appearance. For successful results, however, both the properties of the backing material (for example, strong bricks, no-fines concrete or wood-wool slabs), and the exposure conditions resulting from the situation and design of a building (for example, whether the building is a flat-roofed one with a parapet or whether it has adequate eaves protection), should be taken into consideration in choosing the material, the method of application, and the finish of renderings.

756. Before considering the various backing materials and conditions which affect the choice of renderings, it may be useful to consider the types of renderings available and their properties.

757. RENDERING MATERIALS. In general, rendering mixes consist of a cementitious material and sand in the proportions of 1 : 3 by volume. The cementing material may be Portland cement (normal or rapid-hardening, or white Portland or Portland blast-furnace), a mixture of "run" or hydrated lime and Portland cement, or hydrated hydraulic lime. The sand may be siliceous, crushed limestone sand, or other suitable crushed rock, or foamed slag. The mix may depart somewhat from the 1 : 3 ratio in some cases to suit the fineness of the sand or for other reasons. Typical mixes are as follows:

1. Portland cement : sand	: 3	by volume
2. Cement : lime : sand	: 1 : 5–6	,,
	: 2 : 8–9	,,
4.	: 3 : 10–12	,,
5. Hydrated hydraulic lime : sand	: 2–3	,,

758. High aluminous cement-sand, and high aluminous cement-chalk-sand mixes have also been used, but as they are used for special purposes, as for instance where an oil paint is to be used immediately after rendering, they need not be specially considered here.

759. The cements and hydrated limes are subject to works control and to British Standards and are therefore available as uniform products. The properties of the sand will vary, and both the mix and type of finish of rendering may be affected by the supply available. Where there is a choice, soft sand should be avoided and the harshest sand that can be used by plasterers with any particular backing material is likely to give the best results.

760. APPLICATION. In this country renderings (with the exception of the final coats of roughcast and pebble-dash) are generally applied by laying on the material with a trowel. While there may be some doubt about the claim made that the Continental practice of throwing on the material has, in general, advantages over the traditional English method, the application of an initial spatter-dash coat of Portland cement and sand (1 : 1½ to 1 : 3) thrown on roughly without any

[1] This publication is, unfortunately, out of print at present but may be available for examination through libraries.

subsequent smoothing or levelling, is undoubtedly a good way of applying the first coat to smooth surfaces or to surfaces having uneven suction. Spatter-dash may thus be applied with great advantage on concrete, hollow clay blocks and some clay bricks. The subsequent coats are then applied, after the spatter-dash has hardened, either by throwing or laying on in the usual manner.

761. FINISH. The types of finish used for external rendering may all be described as either: a. Smooth, b. Textured, c. Roughcast, or d. Pebble-dash.

762. Smooth renderings, trowelled or wood-floated, are the most liable to defects, since they tend to craze more readily and show any crazing or cracking more clearly than other types. They are also more difficult to finish to a surface of uniform appearance.

763. Textured renderings, including scraped, torn, and tooled or patterned finishes, have a number of advantages over smooth renderings in regard to crazing and attainment of a uniform appearance, and in many cases are more attractive. They probably require, however, a greater skill in application and have not been so widely used in this country.

764. Roughcast (harling in Scotland) and pebble-dash, which have been widely used on housing, need little comment. Pebble-dash is usually very free from visible defect, as the pebbles hide any crazing or fine cracks very effectively.

765. PROPERTIES OF RENDERINGS. External renderings should:

a. Be durable;

b. Be resistant to water penetration;

c. Maintain a satisfactory appearance.

766. Durability implies in particular a satisfactory and permanent adhesion to the backing and resistance to disintegration by frost and other weakening agencies. The adhesion is influenced by the nature of the surface of the backing material, by the presence (particularly if moisture gains access to the backing materials) of any soluble matter in the backing which may affect the rendering, and by workmanship. Resistance to frost or other weathering action depends upon the strength and porosity characteristics of the rendering, which are in turn dependent upon the mix and the sand grading. Mechanical damage may occur with the weaker types of material or with textured finishes near ground level, and it may be desirable to use a different finish for the lower few feet of a building; this is a normal practice abroad.

767. Water penetration may occur either through the pores in a rendering or through cracks. The importance of penetration through pores depends upon the backing, but may probably in most cases be neglected. If cracks develop, however, penetration may be serious.

768. Changes in appearance of a rendering may result from a number of causes. Cracking, particularly of strong renderings of the smooth or textured types, apart from its effect upon moisture penetration, may be very unsightly, and the "bleeding" of lime from moisture going in and out of such cracks often accentuates the defect. Crazing of the surface of the rendering is particularly noticeable on smooth renderings. The rougher or more broken the surface the less visible and therefore less important it becomes. Deterioration through frost is usually pronounced where it occurs and may necessitate patching. Mould growths may occur in damp positions and can be very noticeable on light-coloured renderings; they probably develop more readily on the weaker and more open textured renderings. Dirt accumulation is a factor in appearance which must considerably influence the choice of material and finish in urban areas. Where an ornamental finish is

employed the pattern of the design may either be destroyed or enhanced by the way in which weathering takes place.

769. INFLUENCE OF BACKING MATERIAL ON CHOICE OF RENDERINGS. The following types of material may be used in external wall construction and require the application of renderings: clay bricks; sand-lime bricks; concrete bricks; hollow clay blocks; dense concrete blocks or slabs; clinker, foamed slag or pumice concrete blocks; cellular concrete blocks; poured dense concrete (including reinforced concrete frames); poured no-fines concrete; poured clinker or foamed slag concrete; asbestos cement sheet; wood-wool slabs.

770. The strength, porosity, roughness or surface texture and content of soluble constituents (and especially sulphates) of the backing materials may influence adhesion and cracking of renderings, and may also affect the degree of protection necessary against rain penetration. Some indication is given in the following paragraphs of the factors which may influence a choice of rendering with these various groups of materials.

771. *Dense, Strong and Smooth Materials.* Amongst the backing materials which may be grouped under this heading are some types of clay brick of low porosity, some dense concrete blocks, poured dense plain and reinforced concrete, and some hollow clay blocks.

772. The smoothness and low porosity of such materials may cause some difficulty in rendering; hacking of the surface may be necessary in some cases to secure adhesion. With all materials of this type a spatter-dash undercoat of cement and sand is probably advantageous in securing adhesion and may obviate the necessity of hacking. Following the spatter-dash any type of mix may be applied and, in so far as compatibility with the backing is concerned, there is no particular preference for any one type. Without a spatter-dash coat the richer lime-cement-sand mixes are probably the best.

773. *Moderately Strong Porous Materials.* Many bricks (including many sand-lime bricks) and many clay and concrete blocks have relatively high suction and porosity and fairly high strength. Such materials can usually be rendered without difficulty with any type of mix. Cement-lime-sand mixes probably give the best results. If the suction is high or irregular the application of a spatter-dash cement-sand undercoating is advantageous.

774. *Moderately Weak Porous Materials.* Blocks or poured concrete made with light-weight aggregate (pumice, foamed slag, clinker), cellular concrete, poured or in blocks and some rather soft or weak bricks (clay or sand-lime) may be described as moderately weak porous materials. On such materials it is important that the rendering should have a lower strength than the surface to which it is affixed, as otherwise the drying shrinkage of the rendering is likely to set up stresses sufficient to tear off the surface of the backing and lead to failure. Cement-lime mixes of the 1 : 1 : 5–6 or 1 : 2 : 8–9 types, or hydraulic lime mixes, are most suitable on such backgrounds: where the design and exposure permit, the mix lower in cement content is probably advantageous.

775. These materials should give no difficulty in application, and with the weaker mixes mentioned should not suffer from loss of adhesion.

776. *Open-textured Material* (*No-fines Concrete*). No-fines (open-textured) concrete is peculiar in that it has a large proportion of voids, but practically no fine pores. It must therefore be considered as a special type of backing material for rendering. The open structure gives a good mechanical key and the material is of sufficient strength to prevent rupture by shrinkage stresses. The type of mix used depends upon the type of finish required: where a smooth or textured rendering is required a 1 : 1 : 5–6 cement-lime-sand mix is probably most suitable; for a roughcast or pebble-dash finish the same mix or a 1 : 3 cement-sand mix can be

used. The rendering should not be thicker than necessary to blind the surface with the first coat and attain the required finish in a second coat; the absence of capillary attraction obviates any necessity for the rendering to be completely damp-proof, and water will only penetrate into the wall through holes, cracks, or defects in the detailing of the structure.

777. In anticipation of a certain amount of leakage due to such defects, it is advisable to provide weep holes through the rendering for drainage purposes in the usual positions.

778. Notes on the use of no-fines concrete are appended to this report (Appendix I).

779. *Weak Resilient Material* (*Wood-Wool Building Slabs*). Wood-wool building slabs which are sometimes proposed for external use have properties necessitating special treatment in regard to rendering. Although of adequate strength when rendered for a cladding material they offer little restraint to the shrinkage or expansion of the rendering with varying moisture content. The adhesion of the rendering is good, but the wood-wool slabs yield to these movements and the rendering can be regarded virtually as a thin slab of mortar without local restraint. If the panels concerned are large (say 10 to 12 ft.) and the edges are restrained, or if the rendering is continuous over the whole wall, it is almost certain that serious cracking will occur; if, however, the panels are relatively small and the edges are free from restraint the risk of cracking is probably not high. Reinforcement of rendering by chicken wire or steel-wire mesh further reduces the likelihood of cracking. Where panels are designed to avoid edge restraint, cracks will appear at the edges, and metal or other suitable expansion joints must be included in the design to prevent rain penetration.

780. The rendering material should preferably be rather stronger than is generally considered desirable on normal backing materials; with the latter a rather weak rendering is desirable to permit local relief of shrinkage stresses, but with wood-wool slabs used in unrestrained panels the object is rather to confine the relief of stresses to the edges of the panel. Either 1 : 1 : 5–6 cement-lime-sand mixes or 1 : 3 cement-sand mixes may be used. The cement-lime-sand mixes are preferable for smooth or textured finishes.

781. *Materials containing Appreciable Amounts of Soluble Sulphates.* Many clay bricks contain appreciable amounts of calcium sulphate which cannot be eliminated in manufacture. Under wet conditions chemical action occurs between the calcium sulphate and some of the constituents of the mortar, leading to loss of adhesion of the rendering and other effects.

782. Common bricks of such types have been widely used for rendered brickwork in buildings of traditional type with overhanging eaves, since the brickwork does not normally remain very moist long enough for any severe trouble to develop. If, however, the brickwork has become very wet during erection owing to weather conditions, it should be given opportunity to dry before rendering is applied, since otherwise a considerable amount of water is locked in the brickwork. Similarly, any features in design which tend to wetness in the brickwork are to be avoided. Even if their frost resistance is adequate, which is not always the case, bricks containing appreciable amounts of sulphate salts are not suitable for use in rendered parapets or other exposed situations. Though no hard-and-fast rule can be laid down, general experience has shown that troubles from sulphate action under wet conditions are rarely found with bricks containing less than 1 per cent. calcium sulphate.

783. INFLUENCE OF DESIGN AND POSITION OF BUILDING ON CHOICE OF RENDERING. The selection of the rendering should, apart from aesthetic considerations, depend in part upon the design and the position of a building. Both the type of mix and the finish to give the best results will depend upon the exposure, whether urban, rural or coastal, and upon the presence or otherwise of

Choice of External Rendered Finishes in relation to Backing Materials and Exposure Conditions

BACKING MATERIAL	—	SEVERE EXPOSURE	MODERATE EXPOSURE	PROTECTED	
				RURAL	URBAN
Strong, dense	Pretreatment	SD	SD	SD	SD
	Mix	(1) or (2) (1) (2)	(2) or (3) (1) or (2) (1)	(3) (1) or (2) (1)	(1) or (2) (2) or (3) (2) (1)
	Finish	(c) (d) (b)	(b) (c) (d)	(b) (c) (d)	(c) (b) (a) (d)
Moderately strong, porous	Pretreatment	Some SD	Some SD	Some SD	Some SD
	Mix, Finish	As above	As above	As above	As above
Moderately weak, porous	Mix	(2) (2)	(2) or (3) (2)	(3) (2)	(2) or (3) (2)
	Finish	(c) (b)	(b) (c)	(b) (c)	(c) (b) (a)
Open textured	Mix	(1) or (2) (1) (2)	(2) (1) or (2) (1)	(2) (1) or (2) (1)	(1) or (2) (2) (1)
	Finish	(c) (d) (b)	(b) (c) (d)	(b) (c) (d)	(c) (b) (d)
Weak resilient	Mix	(1) or (2) (1)	(1) or (2) (1)	(1) or (2) (1)	(1) or (2) (1)
	Finish	(b) or (c) (d)	(b) or (c) (d)	(b) or (c) (d)	(b) or (c) (d)

Pretreatment: SD=Spatter-dash coat 1 : 3 cement-sand.

Mix: (1) 1 : 3 cement-sand. (2) 1 : 1 : 5–6 cement-lime-sand. (3) 1 : 2 : 8–9 cement-lime sand.

Finish: a. smooth ; b. textured ; c. roughcast ; d. pebble-dash

protective features. Only an indication can be given here of some preferences for certain conditions which may be sufficient to act as a guide for more particular application.

784. In an urban area, dirt accumulation will be a factor weighing against some textured finishes. With eaves protection, smooth or preferably lightly textured (*e.g.* scraped) finishes are suitable; without such protection a roughcast finish may have advantages in shedding water and in minimising streaking by dirt. The greater protection in urban areas against frost action, particularly in buildings with overhanging eaves, makes it possible to consider the use of the mixes leaner in cement (*e.g.* 1 : 2 : 8–9), particularly for textured finishes.

785. In rural areas light-coloured textured finishes may be favoured; the mixes for these may be of the 1 : 1 : 5–6 or 1 : 2 : 8–9 types depending upon the exposure and amount of protection given by the design of the building. Roughcast or pebble-dash are satisfactory.

786. In exposed coastal areas the pebble-dash and roughcast finishes have advantages in shedding water, but textured finishes may also be satisfactory. Eaves protection may be the deciding factor in choice of mix, but in general the 1 : 1 : 5–6 is probably most suitable except for pebble-dash which should be in cement and sand. In regions where exposure to frost under damp conditions is very marked it is better not to use mixes leaner than 1 : 1 : 5–6.

787. A table summarising the types of mixes and finishes most suited for different purposes appears on page 129.

PAINT REQUIREMENTS OF ALTERNATIVE BUILDING MATERIALS

788. The painting of all the commonly used building materials will be dealt with comprehensively in the Report of the Paint Study Committee convened by the Research Association of British Paint, Colour and Varnish Manufacturers at the instance of the Ministry of Works; that Report will describe the general nature of paints, the preparation of surfaces and the types of paint recommended for use on each.

789. The purpose of the present note is to compare the painting requirements of certain materials which may be of particular interest in relation to alternative forms of construction which may be used in post-war housing, namely, the steel-work in steel-clad houses, various wall linings and also external concrete and cement rendering, and concrete floors.

790. The comparison takes into account the reason for painting, *i.e.* whether it is needed for decoration only or for some other purpose such as preserving the material, waterproofing or reduction of fire risk, and indicates any special precautions needed to produce satisfactory results. On these materials, as in all painting work, the use of paints of adequate quality and good workmanship are the first essentials for success.

A. EXTERNAL CONCRETE AND CEMENT RENDERING

791. As far as preservation of the material is concerned, concrete and cement surfaces do not require painting; hence, in view of the cost of maintaining large painted areas it would be better, if it were possible, to avoid painting and to concentrate instead on obtaining a decorative finish in the concrete itself or by applying a type of rendering of sufficiently good appearance not to need painting. Such a finish, however, is not easily or cheaply attained on concrete and in practice some form of paint coating may often be needed if only to produce a good light colour. In addition, some types of precast concrete walling units are very porous and, if not rendered, require painting to prevent rain penetration.

PAINT REQUIREMENTS

792. It is not possible to lay down any hard-and-fast painting procedure for the different types of concrete wall surfaces since so much depends upon the type of finish required, the nature and condition of the material and the question of cost. Instead, some account may be given of the various types of paint treatment available for the purpose, *i.e.* oil paints, oil-bound distempers, limewash, cement paints and silicate paints. (The term oil paint is here used to include all the many types of paint based on linseed oil or other drying oil media, ranging from the older types of "straight" linseed oil paint to modern pigmented-varnish types.)

793. The use of *oil paint* on concrete and other cement-containing surfaces is not necessary except to obtain a special finish or where waterproofing is required, and since it presents special difficulties when the concrete is new, oil painting is best avoided during the first year at least. The difficulty arises from the fact that the cement is strongly alkaline and tends to attack and destroy oil paints (especially those of the "straight" linseed oil type), the action ceasing only when the concrete has well dried out. Whenever oil paint is used, special alkali-resisting paints should be employed, but even this may not be sufficient to prevent defects developing if the concrete is damp. The special alkali-resisting paints are usually prepared by heat-treating the oil and incorporating special resins; they are therefore usually more expensive and, in addition, may not be in full supply during the immediate post-war period.

794. "Imitation stone paints" are a special type of oil paint (often having a fair degree of alkali resistance) designed to give a textured finish resembling stone. There were several proprietary brands on the market before the war which were used on surfaces such as concrete, cement rendering, stone and brickwork.

795. The durability of an oil paint finish of any type on concrete depends not only on the quality of the paint and conditions of exposure but also on how successfully the risk of attack by moisture and alkalies in the concrete has been eliminated. With this reservation, oil paints of good quality should last several years under normal conditions of exposure before needing repainting.

796. For a cheaper but less durable form of decoration, oil-bound water paint (*oil-bound distemper*) might be used. This type of paint contains much less oil than ordinary oil paint and is, therefore, less susceptible to alkali attack but more susceptible to the effects of weathering. The ordinary "indoor" grade of distemper is not suitable for exterior use unless fortified by the addition of the appropriate petrifying liquid. Some firms supply special grades for outdoor use, and as the result of war-time experience in camouflage work improved durability may be looked for in distemper of this type.

797. Limewashing with lime-tallow, tinted if desired, is a traditional decorative treatment. It is cheap and effective and improves the appearance of drab walls, but it is necessary to recoat every few years if a good appearance is to be maintained. It may be noted also that a lime coating loses its opacity when wet to a considerably greater extent than other types of coating.

798. A comparatively recent development offering attractive possibilities for post-war use is that of *cement paints*. These are sold in powder form for mixing with water immediately before use and consist essentially of white Portland cement and a waterproofing agent, together with fillers and, sometimes, white or coloured pigments. A small proportion of calcium chloride is often included to adjust the setting of the cement. The absence of oil largely eliminates the risk of alkali attack (although some contain casein, the effect of which is still uncertain) and the fact that the ingredients are cheap and readily available is another advantage. There may, however, be some risk of efflorescence on some types of surface; this would be more conspicuous on the darker shades of cement paint.

799. There is a *U.S. Federal Specification* (TT-P-21) for these paints and the Building Research Station is now conducting a series of practical trials in London on paints made to this specification in comparison with two or three proprietary brands. The cost of the latter at present appears to be rather high in view of the simple nature of their composition.

800. Increased attention has recently been given to *silicate paints* in an attempt to make these suitable for exterior use, but insufficient is known about the developments in this direction to justify a recommendation. In general the silicate paints used as fire-retardant treatments for timber (see paras. 844-8 below) have little weather-resistance owing to the solubility of the silicate binding medium.

B. CONCRETE FLOORS

801. In normal times, concrete floors are not very often painted; they are either left untreated or covered with one of the various floor finishes described in another section. If, however, economic considerations preclude the use of any other finish, painting may be regarded as a possible alternative for use in domestic houses, although one obviously subject to definite limitations. Since, for example, painting does little to mitigate the hardness and coldness of concrete, it would not generally be acceptable for living rooms but might be used in such places as passages and lavatories and, possibly, in kitchens.

802. The chief advantages to be gained by painting are in improvement of appearance and ease of cleaning and in preventing the surface from dusting. As regards durability, experience with floor paints appears to have differed somewhat widely. During the war the general behaviour of floor paints on concrete has not been encouraging, but this may perhaps be accounted for partly by a reduction in the quality of the paints themselves and partly by their being applied and used under adverse conditions. On the other hand, examples have been seen of paints giving excellent service under moderately heavy traffic. Given favourable conditions it is thought that a paint should stand for 6 to 12 months on domestic floors without requiring renewal. By wax-polishing, the life would be prolonged but the wax would need to be removed completely before repainting. Frequent washing with soda or cleaning with abrasive powder, however, shortens the life of the paint appreciably.

803. For satisfactory results it is necessary that the concrete should be smooth, non-friable, dry when painted and not subject to rising damp. Paint applied over rough or uneven areas or on weak concrete wears through quickly and dampness of the concrete is likely to lead to alkali attack and loss of adhesion. Where there is danger of damp rising from the foundations the concrete should be insulated by means of a damp-proof course.

804. Little information is available on the composition of proprietary floor paints. They can be described generally as pigmented varnishes. Recently floor paints based on "aromatic petroleum extracts" have been developed and have given promising results. Examples are now being subjected to traffic tests at the Building Research Station.

C. STEEL-CLAD HOUSES

805. In steel-clad houses correct painting of the steelwork is a matter of first importance not only from the point of view of appearance, but also because it is vital to the durability of the structure.

806. It should be realised, also, that if the paint treatment applied originally (including the preparation of the surface) is inadequate so that the paint deteriorates quickly and allows corrosion to set in, considerable trouble and expense may be involved in putting matters right and frequent repainting may be necessary. It

is essential, therefore, that the best possible treatments should be applied from the start.

807. The painting of the steel cladding, especially, requires careful consideration since, apart from the question of actual damage, rust stains on the exterior paintwork quickly give the house a shabby appearance. Some illustration of the problems involved was provided by the survey of steel houses discussed in Part II of this Report.

808. Precise details of the paint "history" of the steel cladding in a number of the cases are lacking; for example, it is not known what paint, if any, was applied to the sheets before they were delivered to the site. Generally speaking, it appears that the back of the plates was protected (either before or after erection) with red lead and/or bituminous paint, or with bituminous felt stuck on, but the nature of the paint used on the outer face is not known.

809. Reports on the behaviour of external paintwork show that in the case of one type of house, extensive rusting appeared during the first year. This condition was improved by scouring the plates and repainting with red lead and two further coats of paint, but it was still found necessary to redecorate every three years. Finally, the "paint harling" treatment described below was adopted and this has required little attention, other than local touching-up, for the last ten years.

810. On another estate, by contrast, the houses had been painted by normal methods and had been repainted only once, nine years ago, when it was found unnecessary to clean the sheets to the bare metal or to apply more than three coats. The paint is thought likely to last several more years.

811. These experiences show that it is possible to obtain adequate protection by efficient painting, and the first instance quoted is a good example of the result of unsuitable initial treatment.

812. Investigations of the general problem of painting iron and steel have shown that, for success, three main principles must be observed:

a. The surface must be very thoroughly cleaned to remove all mill-scale, grease and rust and be quite dry.

b. The priming paint must be applied immediately after cleaning, before fresh rust forms or the surface becomes damp.

c. The priming paint should contain a high proportion of a rust-inhibitive pigment—*e.g.* red lead paint to *British Standard* 1011–1942.

813. It is very difficult to ensure adequate cleaning on the site either before or after erection, and for this reason it is very desirable that the steel plates should be cleaned at the works by sand or shot-blasting or in suitable pickling baths. Principle b. would then require an immediate application of priming paint also at the works. Preferably the priming paint should be stoved after application, in which case a paint specially formulated for stoving would be needed. It would also be worth while considering the advantage to be gained by applying to the steel, before priming, one of the metallic phosphate treatments, of which several proprietary examples are known—*e.g.* "Bonderising" and "Parkerising."

814. Units of the size and simple shape of the plates in question would lend themselves readily to shop treatment on mass production lines. The additional cost of preparing the plates at the works would be partly offset by a saving in the labour and material involved in carrying out the necessary work on the site and in the cost of maintenance. It is stated that paint applied over properly prepared surfaces will last two or three times as long as that applied over surfaces which have been allowed to rust and given the ordinary hand-cleaning.

815. In this connexion, attention may be called to the severe rusting which often takes place during the transport and storage of unpainted steelwork, especially if it is mishandled. As an example, on one of the estates visited in the course of the survey some of the plates were stated to have been used as "barrow runs" during the erection of the houses. The results of this were apparent in the early rusting of the plates and consequent disfigurement of the paintwork. Plates cleaned, primed and stoved at the works, while they would not, of course, be expected to stand up to such rough treatment, should easily withstand any reasonable hazards of transport and storage.

816. After erecting the plates, a further coat of rust-inhibiting paint, *e.g. British Standard* 1011-1942, should be applied. The surface will then be ready to receive the additional coats needed to produce the desired finish.

817. The type of finish to be adopted is largely a matter of personal preference, assuming that paints of good exterior quality are employed. As has been shown, the durability of the treatment depends to a large extent on the quality of the preparatory work, and if deterioration, when it eventually occurs, is confined to the finishing coat and not accompanied by rusting, renewal is a comparatively simple and inexpensive matter.

818. In view of the excellent results which have been reported from "paint harling," however, and its attractive appearance, it may be of interest to give some account of this method of treatment.

819. "Paint harling" is a process which consists essentially in applying a thick coating of a special lead paint and then throwing on graded granite chips which adhere to the paint and produce a roughcast finish. The granite chips are previously coated with the same paint.

820. The following details of the process were supplied by the Second Scottish National Housing Company (Housing Trust) Ltd., Parkgate, Rosyth, Dunfermline. The method of "paint harling" used on the steel houses erected by that body is the subject of patents (Patent Nos. 447, 305 and 478,021).

821. The surface to be treated must be carefully cleaned of all rust, grease and dirt and a good priming coat then applied; red lead paint is suggested. The paint mixture for the harling consists of 77 lb. white lead, 25 lb. stand oil, and 10 lb. gold size, and it may be tinted if desired. A fairly heavy coat should be applied (say 10 to 10½ oz. per sq. yd.) to provide a bedding for the granite chips. The latter should be graded from ⅛ in. to $\frac{5}{16}$ in. and should be previously coated with the paint mixture in a mechanical mixer, allowing 7 lb. of paint to 1 cwt. of chips. These chips should be coated at least eight hours before they are used. The time which should elapse between application of the mixture and throwing on the chips will vary according to atmospheric conditions, and is best determined by practical experience—the average period is two to three hours. Preferably, men trained to this type of work should be employed.

822. The appearance of steel houses treated by this method is attractive, and examples have been seen which are still in good condition after ten years, having been given no more maintenance than was needed to repair accidental mechanical damage to the coating.

823. Provided the ingredients of the special paint coating (white lead, stand oil and gold size) are in good supply after the war, "paint harling" merits consideration for general use on steel-clad houses.

824. Steel framework for steel-clad houses presents an easier painting problem than the cladding, for, since the framework is generally enclosed, the finish need not be decorative, and the rate of deterioration will be much slower than on exposed work. Protection from corrosion, however, is still important, and the same general

principles in painting apply as those discussed above; the surface must be thoroughly cleaned before painting and, if possible, cleaning and priming should preferably be done at the works. If proper attention is given to cleaning and application of the paint, it is possible to obtain adequate protection by a hot application of a bituminous preparation, or by applying at least two coats of a bituminous paint or a tar-base paint: *British Standard* 1070–1942 describes the latter and its application. It is preferable, however, to use a rust-inhibitive oil primer even if a bituminous or tar-base paint is employed for finishing, but it should be noted that British Standard 1070 recommends that tar-base paint should not be applied over an oil primer before the latter is one month old, since the tar paint, if applied too soon, is liable to soften the primer.

825. On any portions of the framework which are exposed and so may require decorative treatment, oil paint should be used throughout.

D. INTERIOR WALL LININGS

826. The range of materials now available for interior wall linings is so wide that it is not possible to give more than a general indication of their painting requirements. For detailed instructions about the decoration of individual materials reference should be made to the manufacturers.

827. Some types of material, including, for example, plastic veneered fibreboards, might be regarded as self-decorative, and would be painted only to provide a change of decor. Most others, however, would normally be distempered or painted for the sake of appearance and cleanliness. The question of painting to preserve the material would seldom arise except perhaps in the case of plastic-veneered fibreboards used in places where dampness is prevalent, *e.g.* in bathrooms or kitchens.

828. The use of some types of lining involves an appreciable increase in the fire risk, in which case the advisability of using fire-retardant paints may have to be considered.

829. The following brief notes on individual types of wall lining are intended primarily to indicate where the nature of the material suggests modification of normal painting procedure, *e.g.* by reasons of its porosity, alkalinity, etc.:

830. INSULATING BOARD lends itself readily to decoration with distemper or flat oil paint or, if desired, a textured finish can be obtained by using "plastic paint." Since the surface is somewhat rough, a glossy finish is not quite so suitable, but there is no reason why it should not be used if it is desired for special reasons, *e.g.* to produce an impervious easily-cleaned surface.

831. Insulating boards vary in porosity, and the more porous types are very absorbent towards oil paints. As a measure of paint economy it is often recommended that the boards be treated with glue size before painting. This is permissible provided it is realised that wetting the board with size may have the effect of making the fibres swell and so roughening the surface. Where it is desired to avoid this and to obtain as smooth a finish as possible, sizing should be omitted, and instead, absorption reduced by using a "sealing" type of primer.

(Where insulating boards are used the risk of fire needs to be considered (see paras. 686 and 844).)

832. HARDBOARD can be distempered or oil painted, but the methods to be adopted vary in detail according to the make and type of board. It is advisable to consult the makers as to the most suitable priming treatment to secure good adhesion of the coating. The application of lining paper before painting is sometimes helpful.

833. PLASTIC VENEERED FIBREBOARD AND PLASTIC SHEETS. These are often self-decorative. If painting is required, special priming treatment may be needed to secure good adhesion of the paint. The makers should be consulted.

834. PLYWOOD. Normal methods for painting or staining wood can be followed.

835. PLASTERBOARD. Ordinary methods of painting and distempering can be followed. There is no need for a special alkali-resistant primer.

836. RESIN CHIP-BOARDS. There is as yet little practical experience in painting this type of material. Different makes vary considerably in surface texture; some can be regarded as self-decorative.

837. With boards containing large chips the surface texture is often coarse, with large cavities between the chips. This may make it difficult to obtain a satisfactory coating with ordinary paint or distemper, and a better effect might be obtained by using "plastic paint" to produce a deliberately textured surface.

838. Boards made from sawdust, on the other hand, are generally closer-textured and so lend themselves better to painting or distempering. If necessary, a lining paper could be applied first, but it is not yet known whether any special priming treatment is required.

839. WOOD-WOOL SLABS. These have a very open texture and advantage is taken of this in acoustic construction, but as used in ordinary houses the slabs would normally be plastered. They would then be painted or distempered in the same way as other plasterwork.

840. ASBESTOS CEMENT AND "ASBESTOS WOOD" SHEETS. The chief precaution needed when painting these materials is to guard against alkali attack on the paint. The risk of attack is appreciable if the sheets are at all damp when painted or subsequently absorb moisture, *e.g.* by condensation on the untreated face.

841. Distemper is rather less susceptible to attack than oil paint, but is not very suitable for use on the sheets in damp steamy atmospheres, since the porous coating is permeable to moisture.

842. With oil paints it is advisable to apply a special alkali-resistant primer and also avoid the use of pigments which are readily affected by alkalies, such as certain blues and greens—this remark about pigments applies equally to distempers.

843. In any paint system adopted it is important to ensure (by reference to the paint manufacturer) the compatibility of successive coatings, and the same principle applies when repainting. A British Standard for Primers for Camouflage Paints, now in preparation, gives information which is useful in this connexion.

FIRE-RETARDANT PAINTS

844. For war-time Civil Defence purposes silicate paint made to the formula quoted in *B.S./ARP* 39 (or paints affording equivalent protection according to the test specified) has been recommended for the protection of attic timbers, and has also been used on fibreboard linings in many temporary buildings.

845. The specification, however, is concerned solely with fire-protective efficiency and takes no account of the decorative finish of the paint. The standard formula for the silicate paint includes no opaque pigment, and the paint does not completely obliterate most surfaces and consequently has very inferior decorative properties.

846. On the other hand, many proprietary paints which have passed the specified performance test give a more opaque finish of reasonably good appearance. It should be realised, however, that silicate paints as a class produce a hard, brittle coating which can hardly be expected to remain free from cracking and flaking

for an indefinite time on flexible wall linings under ordinary conditions of wear and tear. The same applies in some degree to the paints based on calcium sulphate plaster which satisfy *B.S./ARP* 39.

847. At present, therefore, it is not possible to recommend an efficient fire-retardant paint which is entirely satisfactory in other respects. Attempts have been made in the past, however, to produce such a paint based on synthetic resins and it appears desirable that research in this direction should be continued.

848. Several attempts have been made to produce fibreboards rendered "flame-proof" by impregnation with suitable chemicals. These would offer a possible alternative to silicate paint treatment, but no exact information is yet available on the comparative efficacy of the two methods. It is also uncertain to what extent impregnation may affect the other properties of the boards, *e.g.* their thermal conductivity, strength, acoustic properties and painting requirement.

PAINTING DURING THE IMMEDIATE POST-WAR PERIOD

849. In the period immediately following the war there will be a large demand for paints both for decorating new buildings and also for the restoration of damaged or neglected property. At the same time, however, many of the paint ingredients normally used may, at first, be in very short supply since a considerable number of them are imported. The situation would be only partially relieved by the diversion to general use of materials at present restricted to essential purposes.

850. In anticipation of this the Report of the Paint Committee, already mentioned, will include separate recommendations as to the types of paint to be used in the immediate post-war period as well as those recommended when supplies return to normal. The situation will largely be met by continuing for as long as necessary to adopt the modifications in the composition of paints provided for in the various British Standard War Emergency Paint Specifications and by utilising, where suitable, paints which do not involve imported ingredients, *e.g.* cement paints.

SUMMARY OF REPORT AND CONCLUSIONS

851. The building industry would not be able, in its present depleted state, fully to meet the demands to be made on it after the war. In the immediate post-war period, that portion of the industry concerned with housing will find difficulty in meeting even the most urgent needs, and methods of house construction alternative to the traditional will be required.

852. The first step taken by the Committee was to survey the methods of house construction adopted after the last war to meet similar circumstances, with a view to selecting those methods which have been tried and found satisfactory and which could be recommended with assurance.

853. Detailed examination of these systems revealed varying standards of construction. Some are good; some embody good principles improperly applied; others cannot be recommended. The results of the survey (given in Part II) have, however, been encouraging. They disclose ready to hand different types of construction which, subject in some instances to modification in detail suggested by experience, provide good alternatives. Certain of the promoters already have under consideration improvements advised in the reports of the systems.

854. Some of the systems produced houses that were unattractive; it must be emphasised that good architectural advice should be sought in the development of special methods of construction if such houses are to prove acceptable to local authorities and to the public.

855. It should be noted that most of the experience during the inter-war years was with alternative walling systems. Flooring and roofing systems used were, for the most part, conventional, and these are the subject of further inquiry.

856. The types of walling systems reviewed are briefly assessed below:

CONCRETE WALLING SYSTEMS

857. Many concrete walling systems, either as precast or poured *in situ*, are good alternatives. They give scope for the employment of unspecialised labour, with the possibility of some increase in the speed of erection of that part of the building. It must be realised that the success of concrete construction depends on the careful control of materials and workmanship. The use of certain light-weight aggregates and light-weight concretes has been considered and it is thought that they offer scope for development. At the request of the Committee, the Ministry of Works is inquiring into the possibilities of their extended production (pp. 43–67).

TIMBER CONSTRUCTION

858. In general, timber constructions can be recommended, though limited in application by their liability to greater fire hazard and vermin infestation than normal construction. Experience of the special uses of timber by the aircraft and other industries during the war may well lead to an extension of its application to house construction. The extent to which these types of construction can be used will depend on the availability of suitable timber (pp. 67–73).

STEEL-FRAME CONSTRUCTIONS

859. The steel frame is most logically used in house construction when combined with light external and internal claddings, the use of which would supplement the output of bricklayers and plasterers. Steel-frame construction opens up prospects for the evolution of new methods of floor and roof construction, as well as of walling. The fullest advantage was not taken of these possibilities in the systems reviewed, and steps have been taken towards further investigation and experiment on these lines (pp. 73–80).

METAL-CLAD WALLS

860. With the application of the knowledge and experience now available on problems of thermal insulation and protection from corrosion, metal-clad houses provide alternatives to traditional construction. Those systems in which the metal-cladding was used not only as an external surface but also as part of the load-bearing structure are of considerable interest; a combination of purpose such as this appears to have much to recommend it. The development of both steel-frames and metal-cladding may lead to the employment in housebuilding of labour and factory space now absorbed in war industries (pp. 80–92).

861. Even the foregoing systems may not go far enough to supplement the capacity of the building industry as it stands today. Further systems suitable for labour untrained in the building industry are being encouraged, and several proposals are under examination by the Committee.

SUMMARY AND CONCLUSIONS

862. Part I of the Report contains discussion on basic considerations affecting house construction, together with suggestions for the guidance of designers for a performance basis to ensure adequate strength and stability, thermal insulation, sound insulation and the like. It is thought that this is the first time that such a basis for house construction has been formulated. It was necessary to do so, as, when constructions departing materially from traditional forms have to be considered, it is important to be clear on the essential technical requirements. The fact that designers after the last war had no such guidance was responsible for some of the difficulties then encountered with new constructions. In the interval, much scientific work has been done and practical experience gained. For one reason or another, it may be difficult, particularly in the immediate post-war years, to realise all the suggested standards; nevertheless, they should represent the aim until sufficient further experience has been gained to warrant a review of them. A summary of these standards is given on p. 38.

863. Part III of this Report contains a review of some alternative materials which may be required during a possible temporary shortage of normal materials, and of newer materials which merit further trial with a view to permanent adoption.

864. A co-ordinated programme of research and experiment is necessary to encourage further development of alternative methods, and such a programme has been recommended. The programme is being carried out by the Ministry of Works and the Department of Scientific and Industrial Research, with the close co-operation of the Ministry of Health and the Department of Health for Scotland. A special programme is being undertaken by the Department of Health for Scotland through the Scottish Special Housing Association. Research may reveal advantages in a greater measure of standardisation of units of the structure. Investigation should, therefore, be directed not only to the development of forms of construction and of the use of new materials, but also to that high degree of organisation in the workshop and on the site, which will be essential if the full benefits offered by standardisation are to be obtained.

GEORGE M. BURT, *Chairman.*
J. AUSTEN BENT
LOUIS DE SOISSONS
I. G. EVANS
A. B. GARDNER
L. H. KEAY
J. W. LAING
J. R. MCKAY
A. SCOTT
H. SYMON
F. E. TOWNDROW
JAMES WEST

JUDITH G. LEDEBOER, *Secretary.*

October, 1943.

APPENDIX. RECOMMENDATIONS FOR THE USE OF NO-FINES CONCRETE

I. GENERAL

The efficiency of no-fines concrete construction is discussed in Part II of the Report (p. 43). The purpose of the present notes is to provide recommendations on the use of this form of wall construction, together with some explanatory matter, pending the preparation of a Code of Practice which the Codes of Practice Committee have been invited to undertake.

While enough information is available regarding this form of construction on which to base the present recommendations, laboratory test data are in several respects incomplete. An investigation is being made by the Building Research Station to complete the test data. This covers the following points:

Strength of various mixes.
Strength of wall panels and piers.
Shrinkage.
Thermal conductivity.
Corrosion and adhesion of reinforcement in no-fines concrete.
Internal and external finishings.

The recommendations are thus subject to some possible revision when the results of the investigation become available.

II. DESCRIPTION OF NO-FINES CONCRETE

a. NO-FINES CONCRETE is a concrete composed of cement and coarse aggregate only, the fine aggregate of a normal concrete being omitted so as to leave many uniformly distributed voids throughout its mass.

b. USE OF THE MATERIAL. No-fines concrete may be used for load-bearing external and party walls, partitions and chimney breasts. A rendering on external surfaces of the building is necessary.

c. STRENGTH. It has been found in practice that the compressive strength of no-fines concrete, of the mixes specified in these Recommendations, is sufficient for two- or three-storey domestic construction with the wall thicknesses which are usual for solid brickwork.

The following table gives existing data on the strength of the nearest mixes to those recommended for which tests results are available.

COMPRESSIVE STRENGTHS

AGGREGATE	MIX CEMENT : AGGREGATE	WATER/CEMENT RATIO	CUBE STRENGTH lb./sq. in. at three months	COMPRESSIVE STRENGTH OF AXIALLY LOADED 8′×18″×18″ PIERS [tons/sq. ft.]
Gravel (¾″ to ⅜″)	1 : 10	0·45	860	33 (estimated)
A light aggregate	1 : 6	0·60	410	16 (estimated)
Brickwork	Common bricks in 1 : 3 cement mortar Common bricks in 1 : 3 lime mortar			50–70 30–50 (determined experimentally)

No-fines concrete has not the tensile or shear strength of normal concrete, and should not be subjected to unusual eccentric loads such as might occur under the bearing of heavy lintels, nor to bending stresses such as might be caused in slender piers. It is hoped that it will be possible to make more definite recommendations in this connexion when the investigation now in progress is complete.

The bond strength of no-fines concrete is low, but experience has shown that it may be lightly reinforced to provide the necessary strength over openings. Alternatively lintels may be used.

d. WATERPROOFNESS. A no-fines concrete wall with a suitable rendering and good detailing is comparable to a well-constructed 11-in. cavity brick wall as regards resistance to moisture penetration.

Owing to the cellular structure, capillary attraction in no-fines concrete virtually does not occur, and it has been stated by those with practical experience of the material that water penetration by this means is limited to about twice the diameter of the coarsest aggregate. Thus an external wall of rendered no-fines concrete consists of a wall with no capillary suction, faced by a rendering with some capillary suction, and there is no tendency for water to be drawn into the wall from the rendering. The only danger from dampness is of water entering due to faulty detailing at openings, etc., or through cracks in the applied rendering. Water entering in this way will not therefore be drawn inwards, but will travel downwards towards the foot of the wall, being checked on its way by lintels over openings, etc., when it might flow to the inside of the wall equally as to the external face. It follows that damp-proof courses should be inserted over lintels as in cavity brickwork unless the positions are protected by projecting eaves, and then the damp course should have an upturn to lead the damp outwards. Hence the reason for weep holes shown on the drawings. An improperly made construction joint would also hold the damp. This should be guarded against by such precautions as described in this Appendix (p. 145, 4 c).

e. WEIGHT. The weight of no-fines concrete is some two-thirds of that of a normal concrete with a similar material for aggregate. The hydrostatic pressure on formwork during pouring is considerably lower than with normal concrete.

f. SHRINKAGE, EXPANSION AND DRYING OUT. Practical experience of no-fines concrete with a heavy aggregate shows that the shrinkage on drying out is sufficiently small for blocks of up to four houses to be built without vertical expansion joints. To guard against settlement, however, and to deal with possible increased shrinkage with mixes of other aggregates, blocks of houses should have expansion joints at about 50-ft. centres.

No-fines concrete made with dense aggregate has been found in practice to dry out more rapidly than when light-weight aggregates are used.

g. THERMAL INSULATION. Experience in Scotland has shown that 8-in.-thick rendered and plastered external walls of no-fines concrete with a heavy-weight aggregate may be used without causing either condensation or complaints of coldness from the tenants.

The test results so far available indicate:

i. That the thermal insulation of such a wall is similar to that of a brick wall of the same thickness, rendered and plastered; and

ii. That to be comparable with an 11-in. brick wall, with unventilated cavity and plastered internal finish, the 8-in. no-fines concrete wall with heavy-weight aggregate should have additional insulation, such as an internal finish of wallboard on battens.

iii. That the thermal insulation of a no-fines concrete wall 8 in. thick with a clinker aggregate, rendered externally and plastered internally, reaches the insulation standard of an 11-in. brick wall as described under ii. It should be noted, however, that very special precautions regarding sampling and

testing should be taken with clinker aggregates on account of their possible unsoundness. (See note on light-weight aggregates, p. 120.)

h. SOUND INSULATION. Sound insulation in party walls equivalent to that of a 9-in. brick wall can be obtained by using a heavy-weight aggregate in order to obtain a wall of approximately equal mass per unit area to that of a 9-in. brick wall. A higher value than that given by a 9-in. brick wall is, however, desirable (see Part I of Report, pp. 21, 22); this may be obtained by using a discontinuous construction. (See *Sound Transmission in Building*, by R. Fitzmaurice and W. Allen, published by H.M. Stationery Office.)

i. FINISHES. No-fines concrete provides a good key for rendering or plastering. Walls must be finished externally by a rendering. Internally plaster or other finishes may be used. Any normal rendering or plastering mixes are suitable for application to no-fines concrete.

j. FIRE HAZARD. The personal, structural and exposure hazards presented by a no-fines concrete dwelling are no more than those associated with a brick house of otherwise similar construction, provided that with clinker aggregate care is taken to exclude combustible matter. If wall linings are introduced to provide additional thermal insulation, attention should be paid to the recommendations in Part I of the Report (pp. 28, 40).

k. LABOUR REQUIREMENTS.

i. Unskilled workmen can be quickly and easily taught the correct procedure for mixing and placing no-fines concrete, though it is important that those supervising the training should understand the essential difference between no-fines and normal concrete to ensure that the procedure is properly taught.

ii. Good supervision is required to set out and erect the formwork accurately, to fix the frames for openings, and to provide for services and fixings, and to ensure correct pouring procedure and treatment of construction joints, and particularly to ensure correct mixing and consistency on account of the importance of using the correct water/cement ratio.

As with all other building work, close attention is also necessary to general organisation of the work to ensure speed and economy, but until the most economical routine has been established with new methods of this type, the point requires special emphasis.

iii. Skilled craftsmen are required for the external rendering and plastering.

l. SITE ORGANISATION. As a guide to what is possible by good site organisation, the following examples may be quoted. A gang consisting of 16 shutterers and 32 concretors—this labour being unskilled—with 2½ joiners for fixing door and window frames and laying floor and ceiling timber joists, achieved the following output:

Blocks containing four 3-room dwellings were built from floor level to roof level in four days; on the first day formwork was erected, on the second all ground floor walls were poured, on the third the first floor formwork was erected, and on the fourth the first floor walls were poured.

This output included concrete mixing, but not the final dismantling of the formwork.

As another instance, the same gang of workmen achieved the following output per week:

Three blocks of four dwellings were built from foundation to damp-proof course level, and four blocks, each containing two 5-room houses, from damp-proof course up to roof level.

This output included the pouring of chimneys and party walls.

In the case quoted, the finishing trades tended to lag behind the structural work for lack of similar organisation. Comprehensive progress schedules are thus

particularly desirable for this class of work to take advantage of the quick building of the structure and to ensure synchronisation between all trades.

m. COST. The cost of rendered no-fines concrete walling 8 in. thick is much the same as of 11-in. cavity fair faced brickwork, the cost depending largely on an efficient re-use of formwork and organisation on the site. Such organisation can clearly be more easily attained when the housing scheme includes over 100 houses.

n. LIMITATIONS ON DESIGN. It follows from the general characteristics described above, that when used as a load-bearing wall for domestic buildings no-fines concrete imposes few limitations on design.

The material itself cannot span large openings, but wide windows may suitably be obtained either by spanning the floors in a direction parallel to the window wall, or by the use of lintels as with brick walls.

A simple planning arrangement, which avoids both large concentrated loads, and the cutting up of the walls by many openings leaving slender piers between, will be suited to both the strength of the material and the quickest methods of erecting it.

Since all fixings, holes for services, provision for chimney flashing, and so on, must be provided during pouring of the concrete, all detailed drawings should be prepared before any work is begun. Planning and details should be considered in relation to the type of formwork to be used. A certain measure of standardisation may often be imposed on the planning by economic use of the formwork, but a type of formwork which limits the design to the extent of imposing difficult conditions on planning should not be chosen. (See Part IIIB of this Appendix.)

III. RECOMMENDATIONS FOR THE USE OF NO-FINES CONCRETE CAST *IN SITU* FOR ONE- TO THREE-STOREY HOUSING

A. MATERIALS

1. CEMENT

TYPES OF CEMENT. The cement used should comply with the provisions of the *British Standard* 12 *Portland Cements* or the *British Standard* 146 *Portland Blast-furnace Cement*, respectively current at the time of the building work.

2. AGGREGATES

a. GENERAL CHARACTERISTICS. Any sound concrete aggregate which fulfils the following conditions may be used for no-fines concrete:

i. The aggregate should be free from a coating of clay and dust and the fines thoroughly screened out.

ii. The aggregate should be rounded or roughly cubical in shape and must not be of a flaky character, such as shale.

b. SUITABLE AGGREGATES.

i. *Heavy-weight Aggregates.* Natural aggregates complying with B.S. 882–1940. (See para. 1 of Addendum.) Blast-furnace slag aggregate complying with *B.S.* (*War Emergency*) 1047–1942 *Blast-furnace Slag Coarse Aggregate.* (The uniformity and particle shape of this aggregate make it a very suitable one—see para. 1 of Addendum.)

ii. *Medium-weight Aggregates.* Burnt clay brick aggregates complying with *B.S./ARP* 1, *Heavy Aggregates for Shelters Constructed* in situ, *Part* 3. (See para. 2 of Addendum.)

iii. *Light-weight Aggregates.* Clinker aggregates present advantages in thermal insulation, lightness, availability and cheapness, but it should be noted that clinker has given much trouble when used in external walls owing to expansion.

Clinker aggregate, if used, should comply with *B.S.* 834–1939, Clause 14, and Appendices E, F and G (see para. 3 of Addendum). It is essential to note, however, that clinker aggregates, even from the same source, may vary greatly in quality, and each separate delivery should be sampled and tested at the site unless reliable arrangements can be made by the manufacturer. The grading should be carried out by the manufacturer since the proportion of fines to be screened out is high.

c. SIZE OF AGGREGATE. *Grading.* The aggregate should pass a $\frac{3}{4}$-in sieve and not more than 5 per cent. by weight should pass a $\frac{3}{8}$-in. sieve. Any grading between the above limits is satisfactory.

3. MIXES

a. PROPORTION OF CEMENT. The ratio of cement to heavy-weight aggregate should be 1 cwt. of cement to 10 cu. ft. of aggregate, or roughly a proportion of 1 : 8 by volume.

If a clinker aggregate is used, a mix of 1 cwt. of cement to $7\frac{1}{2}$ cu. ft. of aggregate should be used, or roughly a proportion of 1 : 6 by volume.

b. WATER/CEMENT RATIO. The water/cement ratio affects the strength even more than in a normal concrete and the value to be used on the job should be determined by experiment under working conditions. Sufficient water should be present to ensure that each particle of aggregate is coated with cement grout; any excess will tend to make the grout run and so to fill the voids. The correct water/cement ratio will vary with different aggregates, the light aggregates requiring more water than the heavier non-porous material.

c. CUBE STRENGTH. All mixes should have a minimum compressive cube strength of 200 lb. per sq. in. at 7 days, and 350 lb. per sq. ft. at 28 days.

4. WORKMANSHIP

a. MIXING. Aggregates should be mixed for a short time in a damp condition before the cement and the remainder of the water is added. Mixing should continue for at least one minute after the cement and total water required have been added, and until the mix is uniform in colour and all the aggregate evenly covered with cement grout.

b. POURING.

i. Concrete should be placed as soon as possible after mixing. It must not be allowed to stand, and then be used with the addition of further water to give workability.

ii. No-fines concrete, especially with light-weight aggregates, should not be rammed or punned, but should be rodded sufficiently to ensure that it is properly placed in the formwork. With a correct mix the cellular character will result from the grading, and rodding will not interfere with the proper texture of the material. No-fines concrete, properly mixed, will not flow in the same manner as dense concrete, and tends to form "bridges" over even small obstructions, such as a projecting nail. Light rodding will remedy this and secure an even distribution of the material throughout the wall. Mechanical vibration should not be used.

iii. All walls of each block of houses should be poured in horizontal layers proceeding continuously around the building, and the concrete should not be allowed to pile up at a slope in the formwork while awaiting further deliveries, since this practice results in a diagonal line of weakness in the wall.

c. CONSTRUCTION JOINTS. The bond between new and existing work in no-fines concrete is weaker than in normal concrete. For this reason:

i. Vertical or raking construction joints should not be permitted in this material, except where expansion joints are to be formed. If vertical construction joints were permitted near an external angle of the building, these would seriously weaken the structure.

ii. There should be as few horizontal construction joints as possible, and in consequence lifts should be of full storey height.

In forming horizontal joints, the exposed face of the site concrete should be cleaned thoroughly—*e.g.* with a wire brush—and treated with a neat cement slurry applied by means of a brush. The new concrete should then be poured immediately.

Care should be taken to ensure that the voids are filled at the foot of the lift, particularly where joist ends are in any case bridging the voids over one half of the depth of the wall.

5. FIXINGS AND PROVISION FOR SERVICES

a. FIXING. It is impracticable to nail into no-fines concrete, and fixing blocks and lugs, etc., should therefore be built-in. (See Section D (6).)

b. PROVISION FOR SERVICES. Services should be planned in advance and all holes and chases formed during pouring of the concrete. Cutting away for services is not desirable and, if unavoidable, has to be done with particular care.

6. RENDERING

TYPE OF RENDERING. The external rendering is an essential part of the waterproofness of this construction. Rendering should preferably be of rough-surfaced type, such as a cement roughcast or pebble-dash, and should be sufficiently strong and non-porous to prevent disintegration by frost. A 1 : 1 : 6 cement-lime-sand rendering may suitably be used in the south of Britain and on sheltered sites, while in Scotland a 2 : 1 : 9 cement-lime-sand rendering is suitable.

7. INTERNAL FINISHES

Internally walls may be plastered or finished with a lining on battens, etc., if it is desired to improve the thermal insulation. No-fines concrete walls containing flues should be plastered to prevent the percolation of smoke into adjoining rooms.

B. FORMWORK

1. GENERAL REQUIREMENTS

Any system of formwork which complies with the following requirements will be suitable for domestic work in no-fines concrete.

Formwork should be stoutly designed and of metal or metal-faced. It should not require the cutting, fitting, and nailing of timbers on the site, but should consist of standard and interchangeable units, assembled by bolts or metal clips, or other fixings which can be handled quickly by unskilled labour, and re-used many times without deterioration. The general purpose of these requirements is:

i. To obtain the speed of building, economy in formwork costs, and ease of erection and removal by unskilled labour which are possible when concrete of any kind is poured *in situ* on a large scale.

ii. To take advantage of the low hydrostatic pressure exerted by no-fines concrete on the formwork.

iii. To ensure that while an efficient system of standardisation is used, it does not unnecessarily limit design or erection.

2. RE-USE OF FORMWORK

The cost of formwork per sq. yd. of concrete can be greatly reduced if its repeated re-use is organised, and this advantage is necessary for speed and economical building in no-fines concrete. Formwork complying with the above requirements would facilitate re-use.

3. HEIGHT OF LIFT

Formwork should be such that a full-storey height can be poured in one lift. It is an advantage of this type of concrete that this can be done without the use of heavy formwork, the lateral hydrostatic pressure exerted by the no-fines concrete being roughly $\frac{1}{3}$ of that with a normal mix. It is also necessary to minimise the number of horizontal joints in pouring. (See p. 145, 4 c.)

4. REMOVAL OF FORMWORK

Formwork may normally be removed after three days, and the concrete should not be loaded within this time. If formwork consists of panels fitting within frequent supports, which are well tied together, the panels may be removed within 24 hours, provided the supports remain in place.

C. DESIGN OF STRUCTURE

1. FOUNDATIONS

SPREAD OF FOUNDATIONS. Foundations should be of normal concrete and the same structural considerations apply as for brick buildings. Owing to the low tensile strength of no-fines concrete, special care is necessary in areas liable to subsidence, and reinforcement to foundations should be considered.

2. WALL THICKNESSES

a. EXTERNAL WALLS. External walls should be at least 8 in. thick for two-storey buildings, and for three-storey buildings the ground floor walls should be at least 12 in. thick.

See also notes on thermal insulation, Part II (g) of this Appendix.

If desired, external walls below the level of the damp-proof course may be of normal concrete, at least 8 in. thick.

b. PARTY WALLS. Party walls of no-fines concrete should be at least 8 in. thick. To provide sufficient sound insulation, a heavy-weight aggregate should be used.

See also notes on sound insulation, Part II (h) of this Appendix.

c. PARTITIONS. Partitions of *in situ* no-fines concrete should be at least 4 in. thick whether they are load-bearing or not. Narrow strips of unbuttressed partition wall are undesirable, and sections of 4-in.-thick wall should not be less than 18 in. long. Stability is much improved by cross ties, such as another partition, or even by ceiling joists or the roof being pinned down on top of partitions which have free standing ends.

Non-load-bearing partitions, or those less than 4 in. thickness, may be of no-fines concrete blocks, or of other recognised partition materials.

Where partitions are not of *in situ* no-fines concrete, and these butt against no-fines concrete walls, a bonded or tied connection should be formed, either by means of bond holes or chases in the no-fines concrete wall or by metal bond strips cast into this wall and subsequently bedded between the partition blocks.

3. BEARING OF FLOORS

a. WIDTH OF BEARING. Floors should be given 4 in. bearing on walls and partitions.

b. BEARING SURFACE. Where timber joists or precast concrete floors are used the bearing surface should be levelled up with a continuous strip of cement mortar about 1 in. thick to receive them.

4. BEARING OF ROOFS

a. WIDTH OF BEARING, AND BEARING SURFACE. The bearing required for roofs is similar to that for floors.

b. THERMAL MOVEMENT. The precautions necessary with normal construction as regards top insulation should be taken against the effect on walls of thermal expansion in concrete roofs, which may occur in blocks of four or more houses.

5. MEANS OF SPANNING OVER OPENINGS

a. SMALL OPENINGS. The current practice in Scotland, in housing schemes with either timber or concrete floors and roofs, is to span openings up to about 5 ft. wide in the no-fines concrete walling itself, with horizontal reinforcement consisting of two $\frac{1}{2}$ in. rods above, and two $\frac{3}{8}$ in. rods below the opening. For small openings this may be considered as a satisfactory practice. A strip of woven wire of at least $1\frac{1}{2}$ in. mesh, 14-gauge, bent to a "U" shape, may also provide suitable reinforcement.

Reinforcement should preferably be galvanised, or be painted with a cement wash, to prevent corrosion.

The no-fines concrete walling which forms the lintel should not be less than 9 in. deep.

b. WIDE OPENINGS. When wide openings, say over 5 ft., are required, one of the four following methods of construction should be used:

i. The floors may be arranged to span in a direction parallel to the outside wall, the no-fines wall over the wide opening being reinforced to carry its own weight only.

ii. Reinforced no-fines concrete lintels to carry floor and/or roof loads might be used on spans over 5 ft. but only after establishing their strength by testing on the site, for there is no experience of reinforced no-fines concrete being used as a beam over wider spans than 5 ft., though there is no reason to suppose that this is impracticable.

iii. A precast lintel of normal reinforced concrete or steel, etc., may be used. Twin lintels with a cavity between and the usual cavity damp-proof course may be used in place of one precast concrete lintel, to prevent penetration of water. Alternatively the lintel may be shaped so that the main part of it is set behind and protected by the no-fines concrete wall.

iv. An *in situ* reinforced concrete lintel may be formed as an integral part of a concrete floor.

c. BEARING OF LINTELS. The no-fines concrete wall must not be overloaded at the bearings; lintels should bear on the full thickness of an 8-in. wall, and if necessary a greater thickness of wall should be provided as bearing. The bearing should be levelled up in cement mortar as for floors.

d. REINFORCEMENT UNDER OPENINGS. Horizontal reinforcement in the no-fines concrete is required below all openings.

D. DESIGN OF DETAILS

1. SOLID GROUND FLOORS

USE OF NO-FINES CONCRETE. No-fines concrete with a screeded finish may be used, if desired, to form a sandwich type of floor.

2. FOOT OF WALL

a WATERPROOFING. According to current practice, a damp-proof course is placed in the wall at the usual level, the wall below this level being built from the spread foundations upwards in no-fines concrete. If preferred, the wall from the spread foundations up to damp-proof course level may be in normal concrete. In either case the damp-proof course should be turned up vertically on the inner face of the external wall for at least 3 in., and up to the level of the floor surface. Weep holes at approximately 5 ft. centres should be formed in the external renderings above this damp-proof course.

Theoretically, since rising damp due to capillary attraction does not occur in no-fines concrete, the damp-proof course could be omitted, although there is no experience of buildings constructed in this way. In this case, the damp-proof layer in any solid ground floors should be turned up against the inside face of the external wall for a height of at least 3 in. and up to floor level.

Any external rendering, less than 6 in. above ground level, should be in cement mortar.

3. HEAD OF WALL

WATERPROOFING. The head of external walls should be protected by projecting eaves, or in the case of parapets by a weathered and throated precast coping with a damp-proof course immediately beneath it.

If parapets are used, the waterproof roofing should be turned up against the parapet and protected by a flashing carried through the parapet as a damp-proof course. It is the soundest construction to use a low parapet in which this damp-proof course can also form the bedding for the coping.

4. CHIMNEY BREASTS AND STACKS

a. NO-FINES CONCRETE BREASTS AND STACKS. Flues should be formed by means of 9 in. minimum internal diameter fireclay flue linings, bedded in fireclay mortar, cast into the stack or breast, and should have a cover of at least 6 in. where cast in no-fines concrete.

b. NORMAL CONCRETE BREASTS AND STACKS. Chimneys may be poured in normal dense concrete, when the flues may be formed directly in the concrete with a circular core as formwork. A thickness of at least 4 in. of concrete should be provided round all flues. Light reinforcement may be placed round the flues for a height of up to 6 ft. above the fireplace opening.

c. GATHERING. The gathering or inlet section of the flue, over the fireplace, may be formed in a similar way to the flue by a single fireclay unit, above which the straight flue will fit. Where bends in flues are required, standard bends, which are available, should be used instead of the cutting of straight pipes.

d. WATERPROOFING. Where the roof abuts on chimney stacks the turn-up of the roofing material—or the soakers in the case of pitched roofs—should be flashed in the normal way. When chimney stacks are of no-fines concrete, this flashing should be carried through the stacks as a damp-proof course. When stacks are of dense concrete the flashing may be turned into a groove formed in the stack by the insertion of a shaped core within the formwork. Care should be taken in detailing the coping to ensure a watertight joint between this and any flue lining.

5. WEATHERPROOFING OF EXTERNAL OPENINGS

a. CAVITY DAMP-PROOF COURSES. The detailing of external openings to ensure against damp is, as in other constructions, an essential part of sound practice with this material. As with cavity brick construction, damp-proof courses are necessary over lintels and door and window heads.

b. METAL FRAMES. Metal window or door frames may be fixed direct into openings formed in the poured concrete wall, in which case waterproofness will depend on accurate finishing of the external rendering and mastic pointing against the metal frames. A desirable safeguard against water penetration is to use wide flanged metal frames set against a rebate in the no-fines concrete opening.

c. BUILT-IN SURROUNDS. On exposed sites, the external rendering should finish in a groove in the window surround. To this end, wood, metal, or concrete surrounds to the window frames, designed with a suitable groove, should be built in as the external wall is poured, the surrounds being fixed in place in the formwork.

d. SILLS. Waterproofing of sills is especially important. Except in the case of one-piece sills of wood, metal, or slate, all sills should be laid on a damp-proof course.

6. FIXING OF FRAMES AND FITTINGS

a. TIES. Door and window frames should be fixed by W.I., hoop iron, or expanded metal ties, preferably galvanised, or painted with a cement wash to give protection against corrosion, built in 9 in. and turned down into the no-fines concrete. Where window frames are built in and grooved to provide a bond, further fixings would normally not be required.

b. BLOCKS. Fixing blocks of coke breeze concrete or other suitable material should be cast into the walls to provide fixings where required for light-weight fittings, shelving, skirtings, etc. Heavy fittings, such as W.C. cisterns, lavatory basins, or heavy shelves, or fittings for which the location of fixing blocks would be difficult may, according to current practice, be fixed by means of bolts cemented into or through the no-fines concrete walls, using templates which are standardised for all fittings.

7. PROVISION FOR SERVICES

a. PLANNING OF SERVICES. Services should be planned in advance of the execution of any building work, and grouped as compactly as possible, since cutting away in no-fines concrete is not desirable.

b. CONCEALED SERVICES. Conduits for electric wiring may be cast within the no-fines concrete walls. Switch and plug boxes may be concreted in. Chases over 1 in. in depth should not be formed in the walls owing to the risk of cracking.

IV. ADDENDUM

SPECIFICATIONS FOR SUITABLE AGGREGATES FOR NO-FINES CONCRETE

1. HEAVY-WEIGHT AGGREGATES. *B.S. No.* 882–1940 *Natural Aggregates* requires coarse aggregate to be of naturally occurring gravel or whole or crushed stone, which is "hard, strong, durable, clean and free from adherent coatings."

It shall contain "no harmful material in sufficient quantity to affect the strength or durability of the concrete," or to attack any reinforcement.

Unless proved satisfactory by further tests or general experience, coarse aggregates shall not be used if "the percentage increase in weight due to the absorption of water of a representative dry sample of the material exceeds 10 per cent., according to a standard test, nor if it contains an excess of organic matter as shown by a further standard test."

B.S. (*War Emergency*) 1047–1942 *Blast-furnace Slag Coarse Aggregate* requires the aggregate to be a "hard dense slag having a fine-grain crystalline stony texture,

free from adherent coatings, containing no harmful material in sufficient quantity to affect the strength or durability of the concrete, and complying with the following limitations":

i. *Weight per cubic foot.* The weight per cubic foot to be not less than 78 lb. when tested by a standard method.

ii. *Stability.* The aggregate to comply with a standard test for sulphur unsoundness, iron unsoundness, "falling," "dusting," or "lime" unsoundness.

iii. *Sulphur Content.* (a) The percentage of acid soluble sulphate expressed as SO_3 shall not be greater than 0·7 per cent., and (b) the percentage of total sulphur shall not be greater than 2·0 per cent., according to a standard test.

iv. *Water Absorption.* The percentage increase in weight of the aggregate due to the absorption of water shall not exceed 10 per cent., according to a standard test.

Other requirements cover grading, etc.

2. MEDIUM-WEIGHT AGGREGATES. *B.S./ARP*–1, January 1940, Part 3, for crushed clay brick and tile aggregates, states that bricks should be clean and free from adherent coatings.

Material obtained from demolitions shall only be used by special agreement with the engineer or purchaser.

The percentage increase in weight due to the absorption of water shall be not more than 10 per cent., as tested for natural aggregates.

The content by weight of sulphate sulphur in coarse aggregates, expressed as sulphur trioxide, shall not exceed 0·25 per cent. of SO_3.

3. CLINKER AGGREGATES. *B.S.* 834–1939, Clause 14 and Appendices E, F, and G, for clinker aggregates, requires that the material shall pass a standard test for soundness.

The loss on ignition, expressed as a percentage by weight of the material after drying, shall not exceed 10 per cent., according to a standard test.

The content of soluble sulphate, expressed as a percentage of sulphur trioxide in the original dry powdered aggregate, shall not exceed 1·0 per cent., according to a standard test.

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In July 1943 Mr. R. H. Matthew found it necessary, owing to pressure of other work, to resign from the Committee. Mr. J. Austen Bent, A.R.I.B.A., A.M.T.P.I., was appointed in his stead.

In August 1943 Mr. A. M. Chitty, M.A., F.R.I.B.A., was appointed Technical Officer.

TERMS OF REFERENCE

To consider materials and methods of construction suitable for the building of houses and flats, having regard to efficiency, economy, and speed of erection, and to make recommendations for post-war practice in the light of all relevant findings of the Study Committees co-ordinated by the Directorate of Post-War Building of the Ministry of Works.

MINISTRY OF WORKS

POST-WAR BUILDING STUDIES

1. HOUSE CONSTRUCTION
By an Inter-Departmental Committee appointed by the Minister of Health, the Secretary of State for Scotland and the Minister of Works.

2. STANDARD CONSTRUCTION FOR SCHOOLS
By a Committee appointed by the President of the Board of Education.

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By a Committee convened by the British Plastics Federation.

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17. FARM BUILDINGS
By a Committee appointed by the Minister of Agriculture and Fisheries.

18. THE ARCHITECTURAL USE OF BUILDING MATERIALS
By a Committee convened by the Royal Institute of British Architects.

19. HEATING AND VENTILATION
By the Heating and Ventilation Committee of the Building Research Board of the Department of Scientific and Industrial Research.

20. FIRE GRADING OF BUILDINGS
By the Fire Grading Committee of the Building Research Board of the Department of Scientific and Industrial Research, and of the Fire Offices' Committee.

21. SCHOOL BUILDINGS FOR SCOTLAND
By a Committee appointed by the Secretary of State for Scotland.

22. FARM BUILDINGS FOR SCOTLAND
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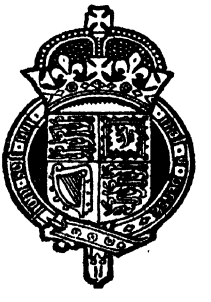
STANDARD CONSTRUCTION FOR SCHOOLS

BY

A COMMITTEE APPOINTED BY

THE PRESIDENT

OF THE BOARD OF EDUCATION



LONDON: 1944

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MINISTRY OF WORKS

POST-WAR BUILDING STUDIES

The series of Reports being published under the title of Post-War Building Studies owes its origin to a desire expressed by professional and other institutions connected with the building and civil engineering industries to assist and support the Ministry of Works in regard to post-war plans. During the latter part of 1941 the then Minister, in order to take advantage of these offers of assistance which he was receiving from all quarters, encouraged the establishment of a series of Committees to investigate and report on the major problems which were likely to affect peace-time building. He also offered, on behalf of the Ministry, to provide the necessary staff and organisation to co-ordinate the various inquiries, in such a way as to avoid duplication of effort and to secure so far as possible uniform direction and policy.

A full list of the Reports which are being issued is given on the back page of the cover.

The Committees were either appointed by a Government Department or convened by a professional institution, a research association, or a trade federation, as seemed most appropriate in each case; and they were so constituted as to ensure that the Reports contain the considered views of experts and others closely concerned with the subject. The Minister gratefully acknowledges the work of the Committees and the valuable assistance given both by the various convening bodies and by the individual members. The Reports are not official publications in the sense that the Government as such is responsible for or necessarily accepts the views expressed, but their contents are authoritative and cannot but be of great value to all concerned with preparations for building after the war.

STANDARD CONSTRUCTION FOR SCHOOLS

To the Right Honourable R. A. Butler, M.P., President of the Board of Education

SIR, We were appointed as a Committee in March 1943, with the following terms of reference: With a view to facilitating the planning and erection of school buildings after the war, to consider the possibilities of applying some measure of standardised construction to schools and to make recommendations as to their planning, layout and equipment.

2. Already, before the appointment of the Committee, a small group of officials of the Board of Education and the Ministry of Works, assisted by a representative of the Royal Institute of British Architects, had been at work for a year on these problems, during which period they had had informal consultations with a number of architects, educational administrators, teachers and others. As a result of the studies thus made, the opinion was formed that there was sufficient evidence and agreement that some measure of standardised construction could usefully and effectively be applied to school buildings to justify the further and more formal inquiries which we were invited to undertake

3. The general background of our problem can be quickly drawn. Even before the war school building fell short of what was needed to complete reorganisation and replace Black List schools. Damage by enemy action and the ban on virtually all school building work during the war have made things worse. After the war, therefore, there will be an immense leeway to make up, to which must be added the demands for new and improved accommodation which must arise from the adoption of any policy of educational reform and reconstruction.

4. It is clear, therefore, that when building operations can be resumed the country will be faced, among other claims, with a demand for school building vastly in excess of pre-war programmes, which were themselves in fact considerably smaller than real necessity required. If, therefore, the restoration and development of the education service is to be achieved with any reasonable speed, all obstacles to the rapid progress of building operations must, as far as possible, be removed.

5. At the same time, with so many competing claims on the building resources of the country after the war—and it is appreciated that housing will no doubt be judged to have a first call on both labour and materials—these resources will have to be used both to the best advantage and with every reasonable economy. Saving of time, saving of labour, and the use of new materials will all have their value. While we fully recognise the urgent claims of housing, we think that it should be regarded as axiomatic that the provision of the necessary school accommodation should be treated as an essential part of any housing development.

6. It is only proper to record here that representatives of the County Architects' Society, who were good enough to discuss our proposals with our Technical Sub-Committee, expressed doubt how far conditions after the war would be such as to make it either necessary or expedient to abandon the traditional materials and methods of building in favour of any standardisation of planning or use of pre-fabricated construction. We ourselves take a different view: the need for school building will, in our opinion, be so unprecedentedly great that it is unlikely that it can be satisfied by normal peace-time methods. We are glad, therefore, that the representatives of the County Architects were in accord with us to the extent that they agreed that, should traditional methods prove insufficient to meet the im-

mediate post-war situation, then the suggestions embodied in this Report should prove of assistance to local education authorities and their architects.

7. Two points would appear in particular to invite attention. The first is that the procedure in force before the war often led to a delay of more than twelve months, taken up in the completion and approval of plans, before the contract was signed and work could be begun on the site. There will, it is suggested, be neither time nor place in post-war school building for such delay.

8. In the second place, if our view of the future is correct, the conditions in which school building may have to be carried on immediately after the war may well demand that something should be sacrificed to the realities of the situation, if thereby more schools can be built and built more quickly. Admitted that ideally each new building should be treated individually and as an end in itself and considered in relation to its particular site and environment; nevertheless, the interest of the children will best be served by securing as quickly as may be a substantial increase of school accommodation, provided always that it is of good design and properly adapted to the requirements of the post-war period. Our suggestions, if wisely carried out, need not involve the sacrifice of anything vital. We recognise to the full the constant educational influence exercised by the physical amenities and aesthetic qualities of the school building. There seems, however, no reason to suppose that the adoption of pre-planning and standardisation, subject to appropriate safeguards, would be incompatible with the production of schools fully satisfactory in both appearance and use. Experience during the war has shown that prefabrication can no longer be regarded as simply an abnormal or emergency method of construction, or that it need result in shoddy or short-lived accommodation.

9. As regards the first point—delays arising from normal administrative procedure —we invited the County Architects' Society to give us some appraisement of the position in the light of their wide experience, and their suggestions for any modifications that might cut out causes of delay and help to speed up the several processes antecedent to the actual work of building. Appendix I sets out the comments and suggestions received, which we believe merit the careful consideration of local education authorities and of the Departments concerned. It will be understood that the Committee must not be taken as endorsing these recommendations or suggestions, either in whole or in particular.

10. Apart, however, from any changes in administrative procedure, we believe that the actual work which precedes the letting of the contract for the erection of a school, and the time taken in securing the necessary approval of plans, could be substantially shortened if it were possible to adopt some system of standardised planning and construction, which would lend itself to the design and large-scale production of units capable of being quickly and economically assembled, so as to provide the accommodation required, and offering such flexibility as will provide for the essential variations between school and school which particular circumstances demand.

11. In this connexion, it should be borne in mind that the basic requirements of schools of the same type are substantially identical. Indeed, it would be true to say that for schools of the same type, and for the same numbers, requirements can be met by accommodation which, in the great majority of cases, is the same; provided that in each case the site is suitable, there is no reason in principle why the same plan should not serve for two or more schools of the same type and size.

12. Standards of accommodation are known to the authorities and have been approved by the Board of Education. The differences, therefore, between schools of the same type do not rest on differences in educational requirements—*i.e.* in the functions that the premises will perform—but on differences of layout and architectural treatment. The main elements of school building are of necessity the

same, falling into three groups, the teaching or classroom accommodation, the practical (including science and art) rooms, and thirdly the communal accommodation represented by hall, gymnasium, dining room, staff rooms, cloakrooms, offices, etc.

13. It is therefore clear that there is already in this business of school planning a very considerable measure of standardisation. There are accepted standards of accommodation in terms of the dimensions of rooms and of the numbers and types of rooms required according to the type of school and the number of pupils to be provided for. While standards now accepted may alter in certain particulars as a result of educational developments, this will continue to be true. We take the view, therefore, that there is no reason to suppose that the application of a measure of standardisation to the construction of schools would involve an undesirable degree of rigidity or uniformity.

14. Having said this, we desire to make it clear that it is not our intention to urge the adoption of some one model plan, or a limited number of layouts, to be used for all schools. Any such suggestion would in any case be impracticable because of the variation of sites. The aim in view is to give such help as may be possible to local education authorities, by evolving methods and designs which will permit of rapid and economic work within the limitations imposed by the restrictions on building that are likely, in our opinion, to be inevitable in the immediate post-war period, when difficulties as regards labour and materials must almost certainly be encountered. We have no doubt that in many cases it will be found that some modification of pre-war practice, so as to make use of prefabrication and of standardised construction, will serve to expedite the provision of accommodation which local authorities will urgently need. Where, however, the local supply of labour and materials makes it possible to carry out the work without loss of time by traditional methods, the local education authority should feel free to do so.

15. Before turning to the details of our suggestions and the diagrams by which they are illustrated, attention should be drawn to two points by way of explanation. In the first place, it is important that the proper use of any methods of standardisation should be clearly understood. If the facilities for economic and rapid construction, which we hope will be made available, are to be turned to the best account, they must be dealt with by a competent architect, well versed in school requirements, who will readily understand in what ways and to what extent any standardised and prefabricated system can be effectively used. He will also readily perceive the various ways in which slight modifications, of advantage in the particular case with which he is dealing, may be adopted without sacrificing the benefits of standardisation.

16. The second point which it is necessary to stress relates particularly to the diagrams illustrating the Report. They must be regarded not as actual plans of schools to be criticised on points of detail; still less as plans embodying decisions of official policy. They are type plans only, intended to indicate the wide variety of treatment and layout compatible with the use of standardised construction. There are, however, certain principles affecting the accommodation of schools to which we attach the greatest importance, though they depart from the standards commonly accepted in recent pre-war years. In the first place, we assume that in the light of the White Paper on Educational Reconstruction the accommodation of what are now known as Modern or Senior Schools should in future march with the standards normally accepted for Secondary Schools. Secondly, in our opinion a classroom should be provided for every class in all types of school, the accommodation given by practical or special rooms being disregarded for the purpose of assessing the classroom accommodation of the school. Thirdly, we regard a separate dining room as essential to meet the development of the provision of school meals. We have kept these principles in mind throughout, and although in

a number of particulars they have not been incorporated in the diagrams accompanying the Report, their inclusion would present no difficulties and would not affect the method of approach which we have adopted.

17. Coming to our actual suggestions, it is necessary at the outset to define our terminology; for convenience, the following terms have been adopted:

a. Structural element—*i.e.* the individual stanchion or truss—the bones or skeleton of the structure.

b. Bay units—*i.e.* the unit of length multiplied by width (or bay), multiples of which make up a room or length of corridor, etc.

c. Plan unit—*i.e.* the room or group of rooms consisting of so many bay units.

d. Plan scheme—*i.e.* the assembly of plan units to form a complete school.

18. The problem before us obviously admits of more than one solution, according to the degree of standardisation in construction that is desired. Two approaches have been selected for study and investigation. The first conceives of the school as a connected structural whole, to which any dimensional factor adopted can be applied throughout. It proceeds direct to the plan scheme. The second conceives of the school rather as a group of separate plan units, which may be left unconnected, or connected by *in situ* work, as desired. Each of these approaches is examined in fuller detail in the paragraphs that follow.

19. The first approach presupposes a general and connected framework to which the whole of the structure must conform. The choice of a unit dimension for this purpose, applicable throughout, is not easy, but, as one of the most generally accepted measurements recurring in a school plan is the length of a classroom, this length—24 ft. in the clear—is considered to offer a good guide for the selection of such a unit. More than one sub-multiple of 24 ft. might be chosen, but the diagrams (Figs. 1 to 5) illustrating this part of our report have been drawn to a unit dimension of 8 ft. 3 in. Three times this unit dimension gives a length of 24 ft. 9 in., and when allowance has been made for wall or partition thickness, three such units would give a clear classroom length of about 24 ft. It is true that the application of this unit to the width of the room would give a clear dimension in excess of the 21 or 22 ft. usually assigned. We are, however, satisfied that, if the necessary dimensions of, *e.g.*, the practical and special rooms are to be observed (*cf.* Appendix II and Figs. 10 to 15), classrooms of this size are inevitable. They would in fact be quite appropriate for the junior school, in which space is a prime requisite. In Modern Schools, with classes of which the maximum size will be 30, they will give more than the 16 sq. ft. per child recommended hitherto for Secondary Schools; but the excess of space over existing standards, which is likely in itself to be welcome, will be very small in comparison with the school as a whole, and would in our opinion be compensated by the other advantages which this method of standardisation offers.

20. Leaving aside this question of the basic dimensional unit that can best be adopted—and we recognise that further investigation may suggest some more convenient alternative—we turn to the kind of construction that will most effectively lend itself to standardised planning; the prefabrication of structural elements and the wider use of prefabricated materials. It is desirable that any system recommended should allow not only for flexibility in planning and layout, but also, so far as possible, for flexibility in the use of materials, whether for the structural elements or for walling and infilling. At the same time, it is necessary to aim at avoiding excessive demands on highly skilled specialist labour. For a connected framework such as we have in mind, we have reached the conclusion that steel is likely to offer the material most readily available and best adapted to the production of the necessary structural elements—stanchions and roof trusses

21. Already before the war the steel industry could, and did, produce standardised units for the frame construction of schools, and we have no doubt that the industry will be able to produce any new or modified forms which the further development of methods of standardised construction may demand. While, therefore, we have no desire to leave out of account any material that offers possibilities of a practical solution, we believe that it is reasonable to assume that, although both concrete and timber could no doubt be used for one-storey construction, steel is the material most likely to be readily available for our purpose, and would have the advantage that it would facilitate the provision of two-storey building. Whether steel should be of the usual solid rolled structural sections or of cold rolled strip steel, or again of some tubular type, is a matter that must be decided in consultation with structural engineers by industrial experts acquainted with modern methods and production facilities. It will be understood that in conjunction with a standard framework of this kind standard window and door frames would also be used.

22. When once the structural framework is erected, the architect will have virtually complete freedom as to the infilling walls and partitions, and the formation of roof and ceiling surfaces. As, however, all these infillings would have a nominal length or span based on the same basic dimensional unit, the process of standardisation could readily be applied to them. There is nothing to prevent the architect from using brick, masonry or blocks of any material for the wall structure below the window sills whatever their height, or for the whole wall panel where it is solid, but there seems little doubt that time and labour may be saved in so far as prefabricated standard-sized wall units could be utilised. It is understood that investigations are being carried out under the Ministry of Works into alternative types of standard wall and partition units.

23. It is not easy in letterpress to make fully clear the exact effect of these suggestions. We believe, however, that the appended diagrams (Figs. 1 to 5 and 10 to 15, the latter showing practical rooms planned according to this system of standardisation) will serve to illustrate the method of construction envisaged and the variety of layout to which it would lend itself. It will suffice here to summarise the advantages which are likely to be derived from the method we have discussed.

a. The structural elements for a steel framework could be produced in large quantity by mass production to standard size or sizes. Actually, the steel uprights, while differing in length according to requirements, would all have the same width so as to permit generally the use of the same infilling panel units. For two-storey construction the design of stanchions may have to be somewhat modified, but it is intended that they should be adapted to permit of the use of the same walling units as the one-storey buildings. As regards roof trusses, which would in any case have to be produced in some two or three spans, we think it desirable that they should also provide a variety of pitch to permit a variety of roofing finishes suitable to different parts of the school, or in keeping with the setting of the school, or local tradition.

b. The adoption of the same basic unit of dimension in either direction—for both length and width—would make it possible to project the layout of the school in any direction desired as a connected whole, and would further make it possible to use prefabricated wall panels or window frames of the same size in either direction.

c. The use of a framework would enable roofing to be taken in hand while walls were still in course of erection, thus saving time on the process of drying out.

d. While we have so far envisaged the school as a whole and as a connected structural unit, the framework contemplated could equally well be used for

separate blocks of classrooms or practical rooms, or for separate halls, gymnasia, etc., where additions are required to existing accommodation, or where the site levels are such as not to permit of a continuous framework being erected for the complete school.

24. In the second approach to the problem, to which as indicated in paragraph 18 we have given consideration, the school is conceived as being not an integrated framework, but as a combination of separate units—plan units—designed to provide for the several requirements of the three main categories of school accommodation, the classrooms, the practical rooms and the communal accommodation. These plan units could be connected up, if the site permitted, by standard corridor connexions, or, where this was impossible, by *in situ* work as might be required.

25. Diagrams have been prepared (Figs. 6 to 9) showing a suggested structural element for one-storey construction which could be manufactured in either steel, reinforced concrete or timber, and giving an illustration of the way in which plan units might be grouped to form a complete school. Each plan unit can be complete in itself, and is capable of being placed in position in any plan scheme independently of any adjoining plan units or structure. The school is thus an assembly of standard units that may be left disconnected or connected, whichever may be most convenient. Such units of classroom blocks or halls, etc. would be found of great service for additions to existing schools, the accommodation of which has to be enlarged or brought up-to-date.

26. As the plan units are regarded as separate entities which can be joined together if required by appropriate links, and not as parts of one connected framework, structural considerations do not make it necessary to base both the width and length of bay units on the same unit of dimension. Thus, in the diagrams appended, the bay unit composing classrooms and practical rooms has a running length of 7 ft. 6 in., with a span of 24 ft., thus effecting some saving of space and materials. Appendix II sets out, for purposes of comparison, the sizes of various rooms indicated in the Board's existing official booklets on elementary and secondary schools, together with the sizes of rooms obtained by the application of the unit dimensions adopted in our several diagrams.

27. The structural element illustrated in Fig. 6 opens up the way to the possible use of materials such as concrete and timber in addition to steel for structural elements. As already stated, we are anxious that no means of securing rapid production or of enlisting the aid of a variety of materials should be overlooked. Both timber and concrete offer certain advantages in that special designs could be carried out without any elaborate preparatory arrangements or special machinery. We are, however, advised that structural elements made in reinforced concrete are likely to involve higher costs of transport than steel; greater risk of breakage and greater difficulties of handling on the site. Local circumstances may, in some cases, make the use of concrete an advantage, but we incline generally to the view that the first suggestions discussed in paragraphs 19 to 23 of this Report are most likely to repay further expert investigation.

28. It will be understood that in no case will it be possible wholly to eliminate all *in situ* work. For example, the boiler house would always be designed as a separate entity and built of appropriate materials on the site. In many cases, too, it may be found necessary or convenient to effect some connexions by *in situ* work.

29. The problem of providing a school on an extremely restricted site is not one which appears to admit of solution on the lines we are advocating. It is to be hoped, however, that restricted sites, which have imposed a continuing liability in so many instances in the past, will in no case be approved in the future. We are advised that even a modern or secondary school for some 360 children, designed entirely or principally on one storey, would not demand a site, for the buildings and the

immediate playgrounds, excluding the playing fields, which could be regarded as in any way extravagant.

30. In considering the problem remitted to us we have throughout directed our attention entirely to the needs of primary and secondary schools. The post-war period will no doubt see a large expansion of technical education, which will necessitate the provision of new Technical Schools and Colleges. Such institutions, however, owing to the variety of their requirements, the scale on which many of them have to be built, and their comparatively limited numbers, would not appear to lend themselves to any system of standardised construction. Each will present its own problem. At the same time, it would appear likely that some of the additional accommodation required for the purposes of technical education could be secured more rapidly, if simple standard units could be designed and produced for workshop, laboratory and classroom blocks, which would be erected and brought into use in advance of the erection of the complete college, with all the amenities which institutions of this character should undoubtedly ultimately enjoy. We have not thought it desirable to consider in detail how far the proposals we make would be applicable to the Young People's Colleges proposed in the White Paper on Educational Reconstruction. We recognise that freedom to experiment in the activities to be provided in these Colleges will be essential: we see no reason to suppose, however, that the system of standardised construction which we advocate could not with advantage be applied to them.

31. We are conscious that our deliberations have not carried us further than a statement of the case for using methods of standardised construction for building schools in the early post-war years, together with suggestions, which are far from embracing the necessary technical detail, as to ways in which such standardisation seems likely most effectively to be attained. The technical problems that remain to be worked out are not such as can profitably be discussed by a body such as our Committee.

32. We desire, therefore, to make two positive recommendations. In the first place, the idea of standardisation in connexion with school building, if unaccompanied by reasoned explanation of its objects and effects, is liable to give rise to misconceptions and to encounter quite unnecessary hostility. We accordingly recommend that steps should be taken to bring before local education authorities and others concerned, the considerations which appear likely to govern school building in the early post-war period, and the consequent desirability of adopting some system of standardisation for school construction.

33. In the second place, while we have no doubt as to the practicability of our suggestions, it will be obvious that further expert consideration will be necessary to determine the design of the best and most economical type of structural elements. This is a matter which we feel should be pursued by the Board of Education and the Ministry of Works in consultation, as may be necessary, with industry. Time will be required for preparation and experiment before full scale production of suitable structural elements can begin. There seems reason to believe that some firms are already studying the possibility of producing structural units on the lines we have in mind, and they would no doubt welcome guidance as to the requirements to be met. We accordingly recommend that the necessary research should be undertaken by the Board of Education and the Ministry of Works with a view to issuing, for the information of local education authorities and their architects, as well as of industry, the more technical detail required for the production of suitable structural elements, accompanied by illustrative diagrams showing the way in which a variety of plan schemes can be evolved, covering a range of schools of different types and sizes. Information should also be made available as to different methods for dealing with both internal and external walling, with particular reference to any possibilities of using prefabricated materials which expert advice may

suggest. In pursuing these inquiries consideration will no doubt be given to such questions as acoustics, insulation against noise, and types of flooring for different rooms.

34. Such information would be of greater value if issued either together with, or as part of, a revised and up-to-date statement of the Board's requirements for schools, in so far as their existing publications, which were issued some years back now, may call for any modification or revision, whether in the light of present standards or prospective educational changes.

35. There remains the third item in our terms of reference: the question of equipment. The term equipment may cover a very wide variety of objects, ranging from fixtures such as the plumbing, sanitary fittings, lighting fixtures, or heating apparatus forming part of the building, to movable furniture such as tables, desks, chairs and other necessary equipment forming no part of the contract for the school building. As regards the fixtures, we understand that researches are now being conducted by Committees working under the auspices of the Post-War Building Directorate of the Ministry of Works, which may lead to some further measures of standardisation designed to facilitate large-scale production and rapid fitting. Their conclusions will no doubt be of great use to schools.

36. School furniture, however, presents a somewhat different problem. It seems reasonable to assume that in the early post-war period shortage of supplies is likely to make it necessary in many cases to use equipment for schools of simple design and made in new materials. This is a matter which, we think, would repay careful study. Such an inquiry, however, could not, we feel, be successfully pursued by a Committee constituted as we are. What is required for the purpose is, we think, a small group of administrators and teachers who would review the matter in detail in consultation with representative suppliers and experienced school architects. We have no doubt that they would receive any help that they may desire from the officers of the Board of Education, and such guidance and assistance as the Departments concerned with the control of materials and production may be able to give.

37. We desire to place on record our thanks to our Secretary, Mr. Maxwell-Hyslop, for his assistance throughout our deliberations, and, more particularly, in the preparation of our Report. We are also indebted to the Ministry of Works, who have met all our requests for the duplication of plans and drawings from which the diagrams illustrating our Report have been selected.

R. S. WOOD, *Chairman.*	F. R. HURLSTONE JONES.
W. P. ALEXANDER.	P. D. INNES.
A. L. BINNS.	THOS. H. JONES.
W. G. BRIGGS.	HENRY MORRIS.
AGNES CATNACH.	W. G. NEWTON.
DENIS CLARKE-HALL.	L. R. PEARS.
FREDA CORBET.	T. J. REES.
H. CROPPER.	J. E. RICHARDSON.
G. ELMER.	C. G. STILLMAN.
W. E. EVANS.	F. W. STRATTON.
OLIVE M. HASTINGS.	THOS. WALLING.
ISOBEL HASWELL.	A. C. T. WOODWARD.
A. E. HENSHALL.	A. R. MAXWELL-HYSLOP, *Secretary.*

18 November 1943.

APPENDIX I

REPORT OF THE COUNTY ARCHITECTS' SOCIETY ON ADMINISTRATIVE PROCEDURE AFFECTING SITES AND BUILDINGS

INTRODUCTION

The County Architects' Society is glad to comply with the request of the Board of Education to review administrative procedure and to make suggestions to eliminate delay which would hinder the post-war building programme.

REVIEW

All members of the Society have been circulated and asked:

a. To describe the procedure applying to their own county.

b. To define what have been in their experience the main causes for delay.

c. To make suggestions for the speeding up of procedure.

ITEMS OF DELAY

Although procedure is found to vary slightly under different authorities, there is a large measure of agreement on the part of the Society on the causes for delay, which have been mainly of an administrative character. The greatest loss of time seems to have been due to the following factors:

a. Selection, valuation and acquisition of sites.

b. Approvals of plans by the various authorities concerned, including discussions and agreement with the Board, its experts, its Inspector for the area, and local experts.

c. Delays arising in the consideration of tenders, after public advertisement, where the standing of a firm is in question.

d. With a normal architectural staff, delay should not result from the time taken in the preparation of the necessary drawings and bills of quantities. It must be pointed out, however, that in the past the preparation of drawings has frequently had to await the conclusion of the varied negotiations already referred to in paragraph (b) above.

RECOMMENDATIONS

These and other causes of delay have been discussed in detail, and the following condenses in summary form recommendations which the Society submit to the Board as headings under which existing procedure can be reviewed and, it is believed, simplified.

In working out revised administrative details and in simplifying future procedure there may be matters calling for more complete discussion, in which case the County Architects' Society will be happy to place its services at the disposal of the Board.

1. ACQUISITION OF SITES

It is recommended:

That each authority be encouraged to empower a special committee to negotiate the acquisition of sites, if necessary in consultation with an officer of the Board of Education empowered to give immediate approval on their behalf.

In this connexion it may be pointed out:

a. That the difficulty in reaching agreement with local owners has in the past absorbed very much time and denied entry to the site for surveying and levelling. The present position is that compulsory powers to purchase cannot be exercised until the Board of Education is satisfied that no other suitable sites are available in the district. (It is, of course, realised that the Scott and Uthwatt Reports deal with this matter.)

b. That District Valuers should be granted facilities and urged to give expedition to the consideration of site values for projected schools. It has been evident in some counties that District Valuers have experienced difficulty in waiving the claims of agriculture when considering the demands for a site for educational purposes.

c. That the Society feel that this opportunity be taken of stressing the need for local planning so that schools shall be sited in appropriate positions in relation to other building schemes and the reorganisation of urban and rural areas.

2. PLANS

It is recommended:

a. That to avoid the cumulative effects of any delay in time absorbed in concluding negotiations for the acquisition of a site, immediately it has been decided to build a school and whilst the purchase of an agreed site is being negotiated, right of entry be granted and the preparation of working drawings proceed without waiting for the completion of negotiations and possession of the site, which would be assured to the local authority.

b. That the deliberations of the Board's Committee now sitting will include, *inter alia*, the essential requirements not only of type planning in its widest sense, but definition of the layouts of all special rooms, with their components and fittings sufficiently detailed to indicate the broad lines on which sketch plans can be developed with assurance that approval will be forthcoming.

   i. Much time has been absorbed in the past by agreeing with the Board's experts on school data, particularly in the layouts of rooms, special equipment, types of heating and lighting, etc., or in reconciling local needs with the wider national outlook of the Board.

   ii. The time taken by the Board of Education in approving sketch plans appears to have varied, and the effect in some instances has caused an appreciable delay before progress could be made with the working drawings and quantities, with subsequent delay in securing approval of working drawings. It is believed that the acceptance of the standards suggested above will materially relieve the Board of Education's own staff in approving sketch plans.

c. To avoid multiplicity of approvals required before building operations can commence, the Society suggest that arrangements be made between the Board of Education, the Ministry of Health, and the Ministry of Planning (if involved) that the one approval of the Board of Education shall suffice.

The following summarises the present position:

i. Instructions from the Education Committee to acquire a site for the purpose of erecting a new school.

ii. The submission of alternative sites to the Education Committee for approval.

iii. The request for the District Valuer's report on the approved site.

iv. Approval from the Board of Education to the purchase of the site.

v. Approval from the Education Committee to sketch plans for the new building.

vi. Approval of the Board of Education to sketch plans.

vii. Submission of working drawings for approval by the local sanitary authority in respect of drainage.

viii. Submission of plans to the highways authority for approval under the ribbon development schemes.

ix. Submission of plans to the Joint Planning Authority for approval under the Town and Country Planning Act.

x. Submission of working drawings and tenders to the Education Committee.

xi. Submission of working drawings and tenders to the Board of Education.

xii. Submission of tenders to the County Council.

d. That County Councils, in formulating annual estimates—including a block grant approved by the Board of Education to cover their school building programme for the entire year—be empowered to make application to the Ministry of Health for sanction to the borrowing up to this total amount without having to make individual application in respect of each school, and that it be unnecessary to apply for a supplementary estimate in respect of any one or more individual schools until the whole of the amount included in the annual estimate shows signs of becoming exhausted.

3. APPROVED SCHEMES

The Board is recommended to revert to the procedure followed prior to the issue in August, 1928, of Administrative Memorandum No. 61, when it was the practice of the Board to approve schemes upon the submission of sketch plans and approximate estimates of cost. The authority was then free to proceed with the work immediately tenders had been obtained, subject only to a revised application being made for approval if tenders received were in excess of the approved estimate. (In this connexion, a greater margin of latitude in estimating costs should be allowed until the post-war building industry and building costs have become stabilised.)

See Recommendations, paragraph 2 d. above.

4. NOTICES

It is recommended that the period of notice of the intention to build a new school be reconsidered.

5. PROGRAMME

It would appear desirable for the Board to work out now, and well in advance of demobilisation, a steady programme of work, spread over a reasonable period without fixing too rigid a time limit, to enable local education authorities to secure their sites and to envisage their future architectural requirements.

6. QUOTAS

It is anticipated that the Board will make arrangements for local education authorities to be assured of an adequate quota of controlled materials and labour to enable a steady flow of school building work to be maintained.

7. METHODS OF TENDERING

a. The majority of County Councils have accepted the model Standing Order of the Ministry of Health, which demands the acceptance of the lowest tender unless good cause can be shown to the contrary. In practice it has proved almost impossible for an authority on the advice of its officers to commit itself to a categorical statement regarding the inability of a firm to be entrusted with a contract for which its tender is the lowest. The County Council therefore safeguards itself by entering into a bond for the due completion of the work which, with the necessary inquiries and subsequent procedure, has frequently involved considerable delay. The possible lack of experience of the firm, or the unsatisfactory nature of the work it is carrying out, may manifest itself as the contract proceeds, and the date of anticipated completion is often seriously extended.

The Board of Education is therefore invited to consider the advantage of:

i. Restricting tenders either from firms on an approved list, or

ii. Where advertisements have been issued, to formulate safeguards to encourage local education authorities to recommend that County Councils should permit them to select the builder whom they regard as best fitted to undertake the work, provided that the amount of the tender, submitted in open competition, is after analysis found to be fair and reasonable.

b. The Society is strongly of opinion that under normal conditions the preparation of bills of quantities and the acceptance of firm lump-sum tenders is preferable to any other method under which tenders are accepted and work is carried out. Under stable labour conditions very little, if any, initial delay has been caused by the preparation of bills of quantities, which have ensured much saving at a later stage, and particularly in the settlement of final accounts.

c. The only alternative, which the Society would reluctantly accept but cannot recommend, would be to continue for a defined period one of the methods at present used under duress of war-time conditions, in replacing the method tried and proved over a long period of years—*i.e.* firm tenders on quantities. Probably the most innocuous is the method by which competitive tenders are based on a prepared schedule of current prices obtaining in the County or district. This method provides that the competing contractors submit to the Committee the percentage above or below the schedule of prices at which they would be prepared to undertake the work. The anticipated total cost, based on the schedule of the successful contractor, would be submitted to the Board by the local authority and subsequently measured up to ascertain actual and final costs. This, however, would have to be reconciled with paragraph 3 above, also recognition of the danger of an accumulation of work to the quantity surveyor, with possible delay in the adjustment of final accounts.

8. MINOR WORKS

It is recommended that H.M.I. (who was empowered to authorise expenditure only up to £300 before the war) should be given authority, without prior reference to the Board, to approve all expenditure up to a substantial amount to enable rapid headway to be made with improvements to existing premises and new projects of a minor nature.

APPENDIX II

APPROXIMATE NET DIMENSIONS OF ROOMS

1. As recommended in the Board's Educational Pamphlets 86 (Secondary Schools) and 107 (Elementary Schools).
2. Resulting from the application throughout of a unit dimension of 8′ 3″ (Paragraphs 19 to 23).
3. Resulting from a uniform span of 24′ and a running dimension of 7′ 6″ (Paragraphs 24 to 27), except for hall and gymnasium.

TYPE OF ROOM	TYPE OF SCHOOL	1	2		3	
		APPROXIMATE NET DIMENSIONS	a NUMBER OF 8′ 3″ UNITS IN EACH DIRECTION	b APPROXIMATE NET DIMENSIONS	a NUMBER OF 7′ 6″ RUNNING UNITS SPAN 24′	b APPROXIMATE NET DIMENSIONS
CLASSROOM . .	a. Nursery	22′×27′ 24′×25′	3×3	24′×24′	3	24′×22′ 6″
	b. Infants Junior Senior	21′ 6″×24′ 3″	3×3	24′×24′	3	24′×22′ 6″
	c. Secondary (for 30 children)	21′ 6″×22′ 6″ 20′×24′	3×3	24′×24′	3	24′×22′ 6″
PRACTICAL . . DOMESTIC SCIENCE . MANUAL INSTRUCTION CRAFT . . . ART . . . SCIENCE . . .	Infants Junior Senior Secondary	from 600 sq. ft. =24′×25′ to 960 sq. ft. =24′×40′	3×3 3×4 3×5 4×4	24′×24′ 24′×32′ 3″ 24′×40′ 6″ 32′ 3″×32′ 3″	4 5 6	24′×30′ 24′×37′ 6″ 24′×45′
HALL . . .	Infants Junior Senior	30′×60′ +stage	4×7 * 4×8	32′ 3″×57′ 32′ 3″×65′ 3″	SEPARATE SPAN 30′ OR 40′ AND RUNNING LENGTH 10′, THEN ACCORDING TO TYPE AND SIZE OF SCHOOL	
	Secondary	6 sq. ft. per pupil	ACCORDING TO SIZE OF SCHOOL			
GYMNASIUM . .	Senior Secondary	30′×60′	4×7 * 4×8	32′ 3″×57′ 32′ 3″×65′ 3″	AS FOR HALL	

* These dimensions presuppose that the hall and gymnasium will form part of the connected structural framework of the school. If it should be found more convenient to treat them as separate units (*cf.* column 3 above), the most convenient unit dimension would be 10′ instead of 8′ 3″.

GENERAL NOTES ON ILLUSTRATIONS

The following fifteen diagrams have been prepared to illustrate the different approaches to the problems of standardisation discussed in the text of the Report, in order both to show in outline the structural principles underlying the suggested methods of construction and also to provide illustrations of the application of these principles to the assembling of plan units into plan schemes and the layout of individual rooms.

Two points must, however, be borne in mind when the diagrams are being examined. The first is that any assembly of plan units shown as forming part or the whole of a school is purely illustrative of the kind of grouping of which these methods will admit. The same units could be grouped in an endless variety of ways, and this, together with the external treatment of the building, would be left to the unfettered discretion of the architect employed in the building of the school. Equally, there is no suggestion that authorities should feel bound to use any of the plans or methods illustrated.

The second point is that, since these diagrams are only illustrative of structural principles, they must not be taken as in any way indicating standards of accommodation which the Board would approve or which they would necessarily regard as suitable for post-war schools.

GENERAL NOTES TO FIGS. 1–5 (Paragraphs 19–23)

These five diagrams illustrate both the structural framework, and the results of its application to plan schemes, of the system of standardisation described in these paragraphs. Figs. 1 and 2 illustrate structural details. Figs. 3, 4 and 5 show the variety of arrangements in which the same plan units can be grouped.

Figs. 3 and 4 each show a modern school for 360 pupils (30×3×4). A separate classroom is not shown for each class, but the extra rooms could easily be added, as could a dining room. When these drawings were first prepared, separate dining rooms were not contemplated, and the arrangements and planning of the kitchen must accordingly be considered tentative.

In each case the room dimensions given are gross dimensions, and make no allowance for wall thicknesses. For the net dimensions, see Appendix II.

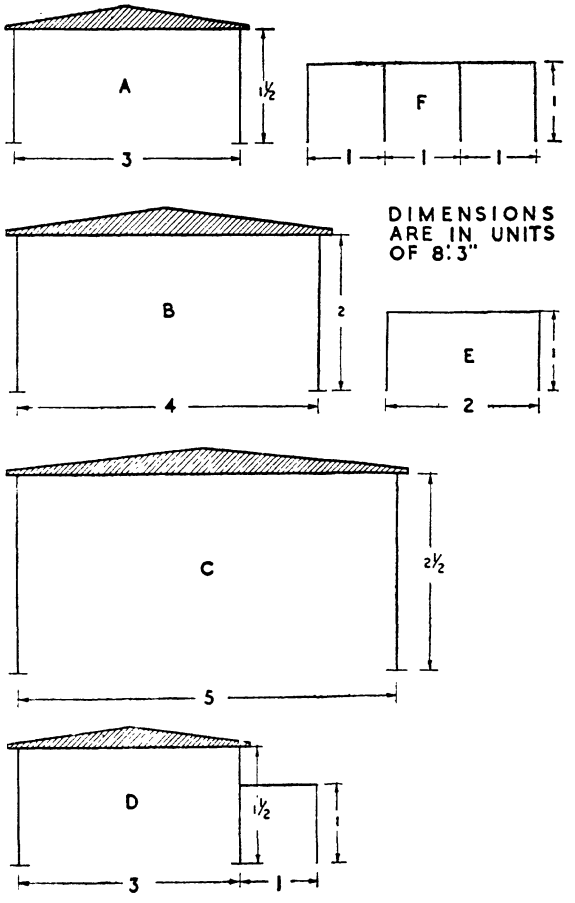


FIG. 1

This diagram shows sections through different sized plan units and corridors. Although a flat pitched roof is shown, roofs could be designed with varying pitches. The widths of rooms are respectively :

A. 3 bays : 24′ 9″
B. 4 bays : 33′
C. 5 bays : 41′ 3″
D. 3 bays : 24′ 9″; and corridor 1 bay : 8′ 3″
E. 2 bays : 16′ 6″
F. 3 single bays each 8′ 3″

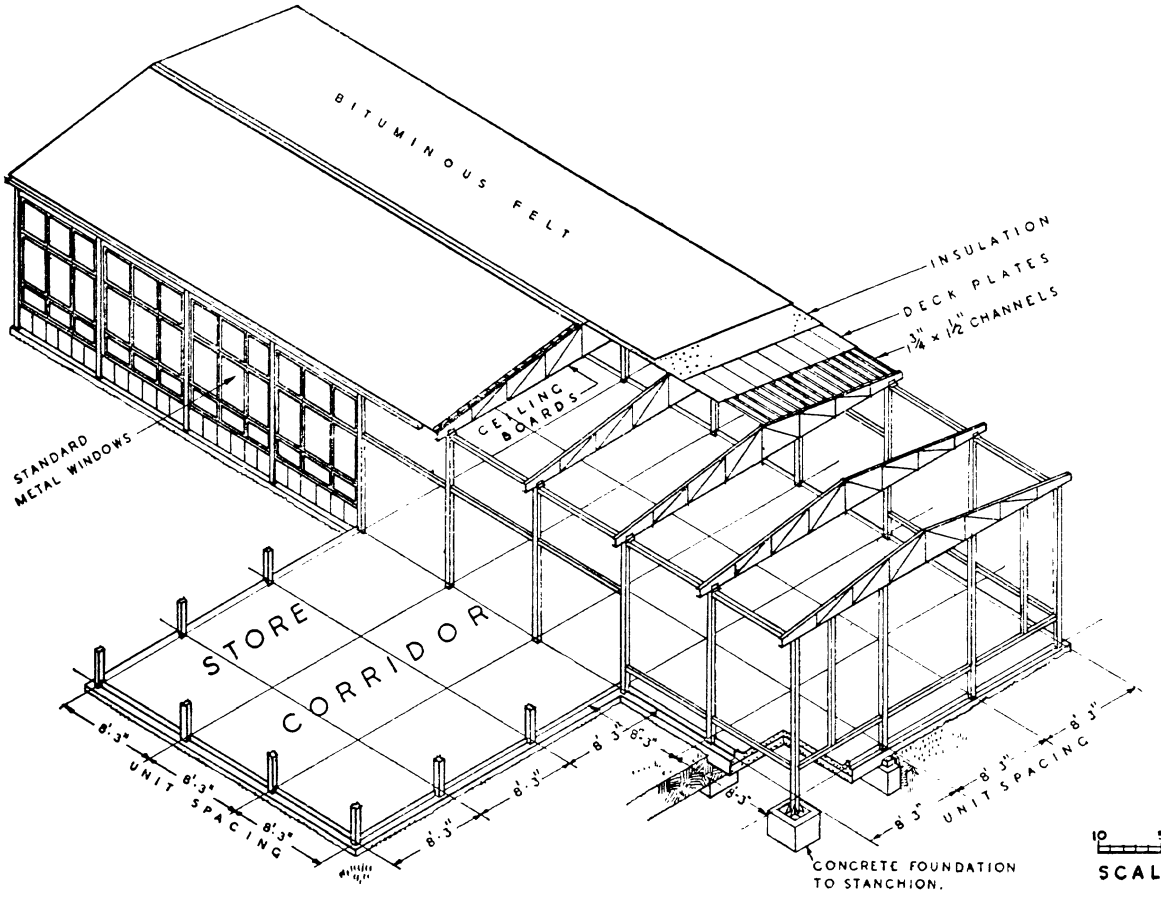


FIG. 2

This isometric drawing shows the structure of the skeleton of a sample plan unit. The structural elements which form the framework of the bay unit will consist of a light form of steel stanchions and roof trusses and transverse members.

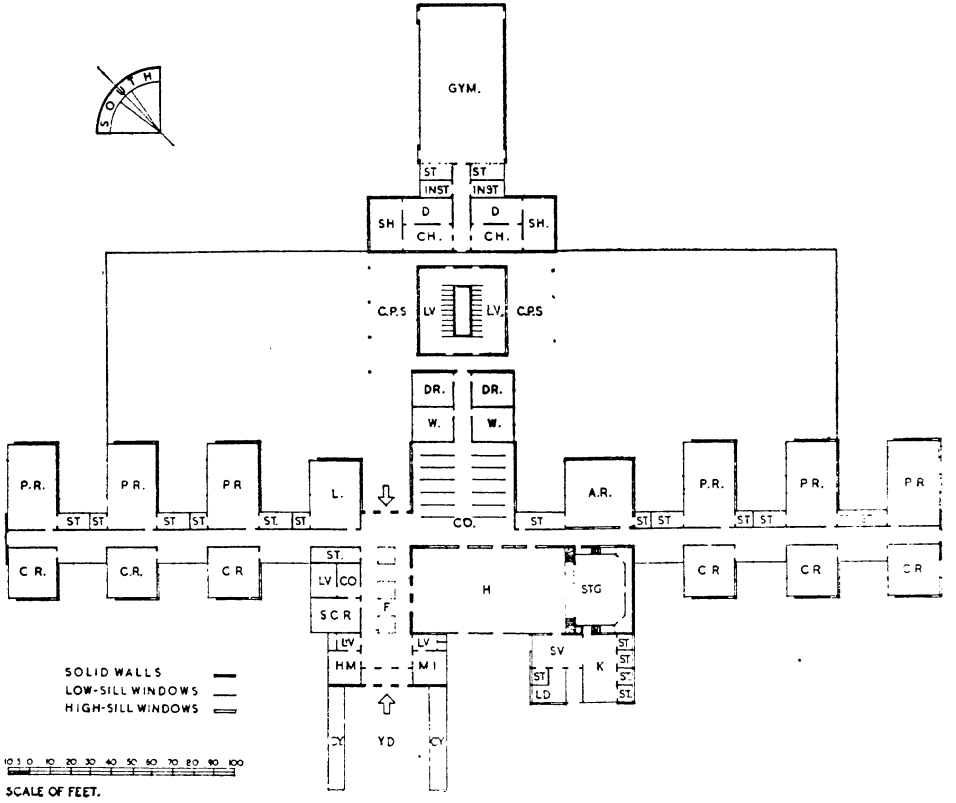


FIG. 3

Modern School for 360 children. A classroom is not shown for each class, but the necessary additions could easily be made.

Accommodation actually shown :

6 classrooms	24 ft. 9 in. × 24 ft. 9 in.	= 613 sq. ft.
6 practical rooms	24 ft. 9 in. × 41 ft. 3 in.	= 1020 sq. ft.
1 Art room	33 ft. × 33 ft.	= 1089 sq. ft.
1 Library	24 ft. 9 in. × 33 ft.	= 816 sq. ft.
1 Hall	74 ft. 3 in. × 41 ft. 3 in. plus stage.	= 3062 sq. ft.
1 Gymnasium plus stores, cloakrooms, changing rooms, lavatories, etc.	74 ft. 3 in. × 41 ft. 3 in.	= 3062 sq. ft.

All dimensions are gross, and take no account of wall thicknesses.

REFERENCES

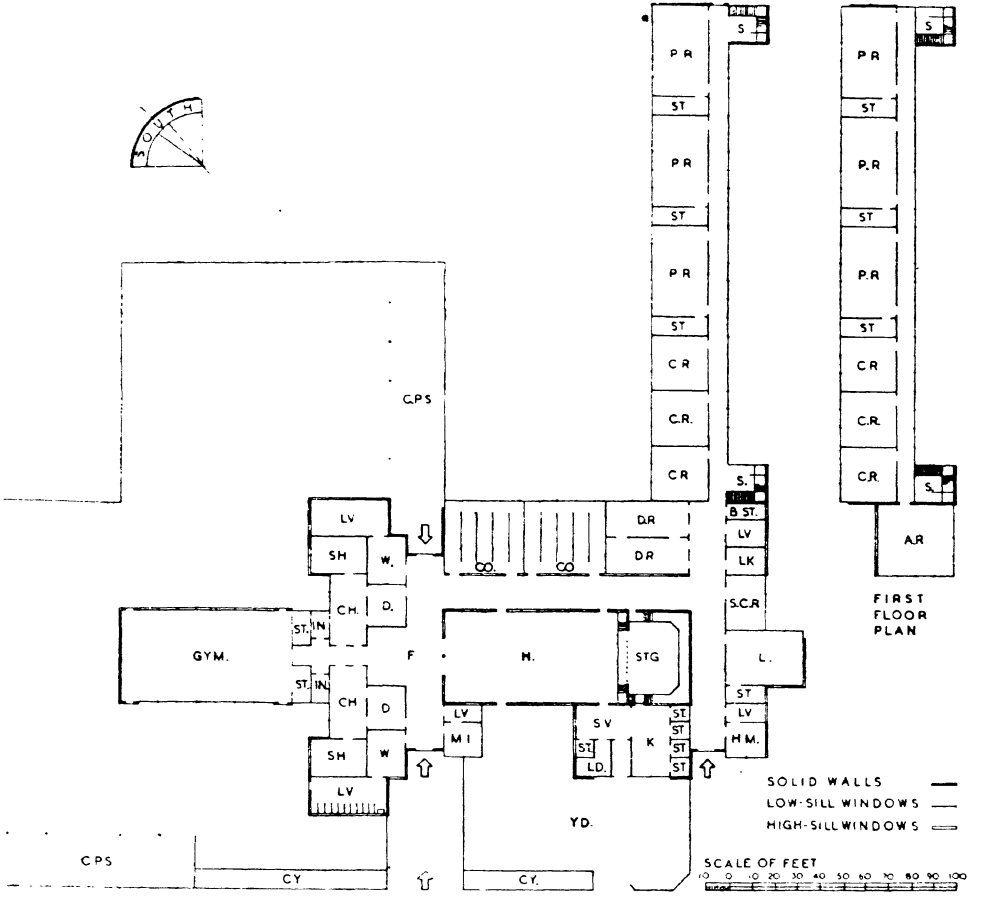
A.R.	Art Room	K.	Kitchen
C.P.S.	Covered Play Space	L.	Library
		Ld.	Larder
Ch.	Changing	Lv.	Lavatory
C.R.	Class Room	M.I.	Medical Inspection
Co.	Coats	P.R.	Practical Room
Cy.	Cycles	S.C.R.	Staff Common Room
D.	Drying		
D.R.	Drying Room	Sh.	Shower
F.	Foyer	St.	Store
Gym.	Gymnasium	Stg.	Stage
H.	Hall	Sv.	Service
H.M	Head Master	W.	Washing
Inst.	Instructor	Yd.	Yard

FIG. 4

Accommodation shown identical with that in Fig. 3; but it will be observed that this diagram shows the classrooms and practical rooms in a wing of two-storey construction. This amount of two-storey building is possible with this type of steel framework, although it is not possible to carry two-storey building much beyond this point. The method of standardisation is not applicable to full multi-storey building.

REFERENCES

A.R.	Art Room	L.	Library
B. St.	Book Store	Ld.	Larder
C.P.S.	Covered Play Space	Lk.	Lockers
		Lv.	Lavatory
Ch.	Changing	M.I.	Medical Inspection
C.R.	Class Room	P.R.	Practical Room
Co.	Coats	S.	Stairs
Cy.	Cycles	S.C.R.	Staff Common Room
D.	Drying		
D.R.	Drying Room	Sh.	Shower
F.	Foyer	St.	Store
Gym.	Gymnasium	Stg.	Stage
H.	Hall	Sv.	Service
H.M.	Head Master	W.	Washing
In.	Instructor	Yd.	Yard
K.	Kitchen		



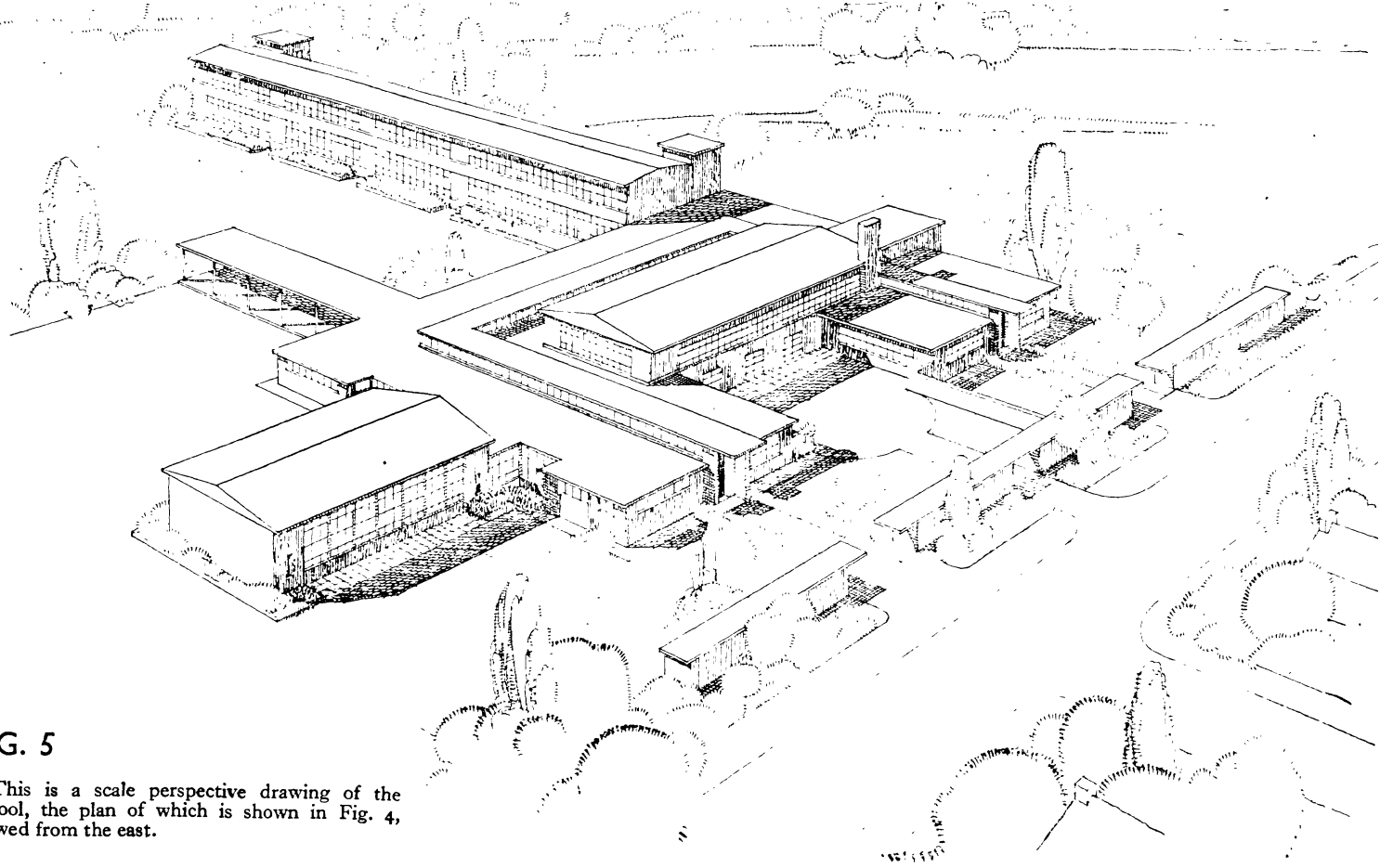


FIG. 5

This is a scale perspective drawing of the school, the plan of which is shown in Fig. 4, viewed from the east.

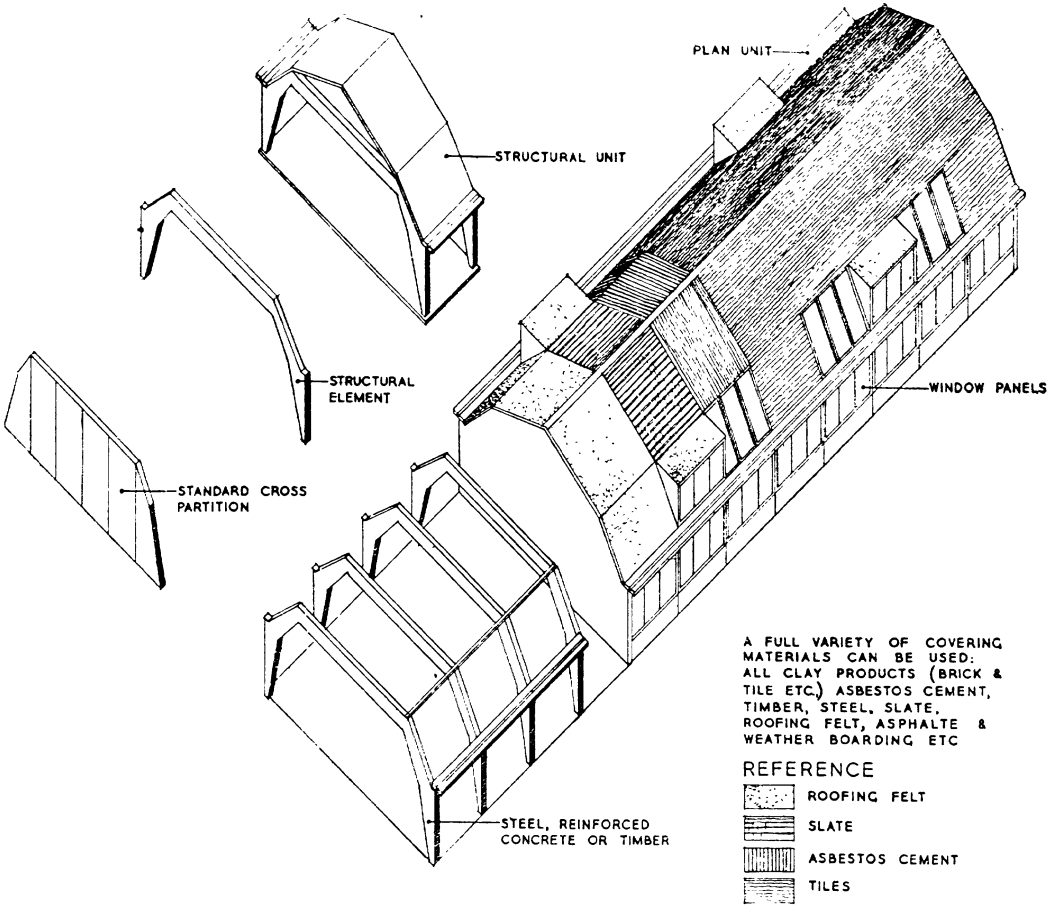
GENERAL NOTES TO FIGS. 6–9

(Paragraphs 24–27)

These four diagrams illustrate the principles described in these paragraphs, which may be described as the building up of rooms, corridors, etc., from a number of structural units of uniform widths and running lengths for the teaching rooms, communal rooms, and corridors respectively. These structural units are combined to form plan units.

FIG. 6

The structural element, which is the framework of the unit and which is illustrated in this diagram, has been given an overall shape which it is thought would best lend itself to the economic use of different types of steel, of timber, or of reinforced concrete. The illustration is "symbolic" in that its actual design and dimensions would be worked out by detailed research. The shape, with its sloping sides, also allows for bi-lateral lighting, if and where required, and lends itself to different treatment of roof-covering materials as shown in Figs. 6 and 7.



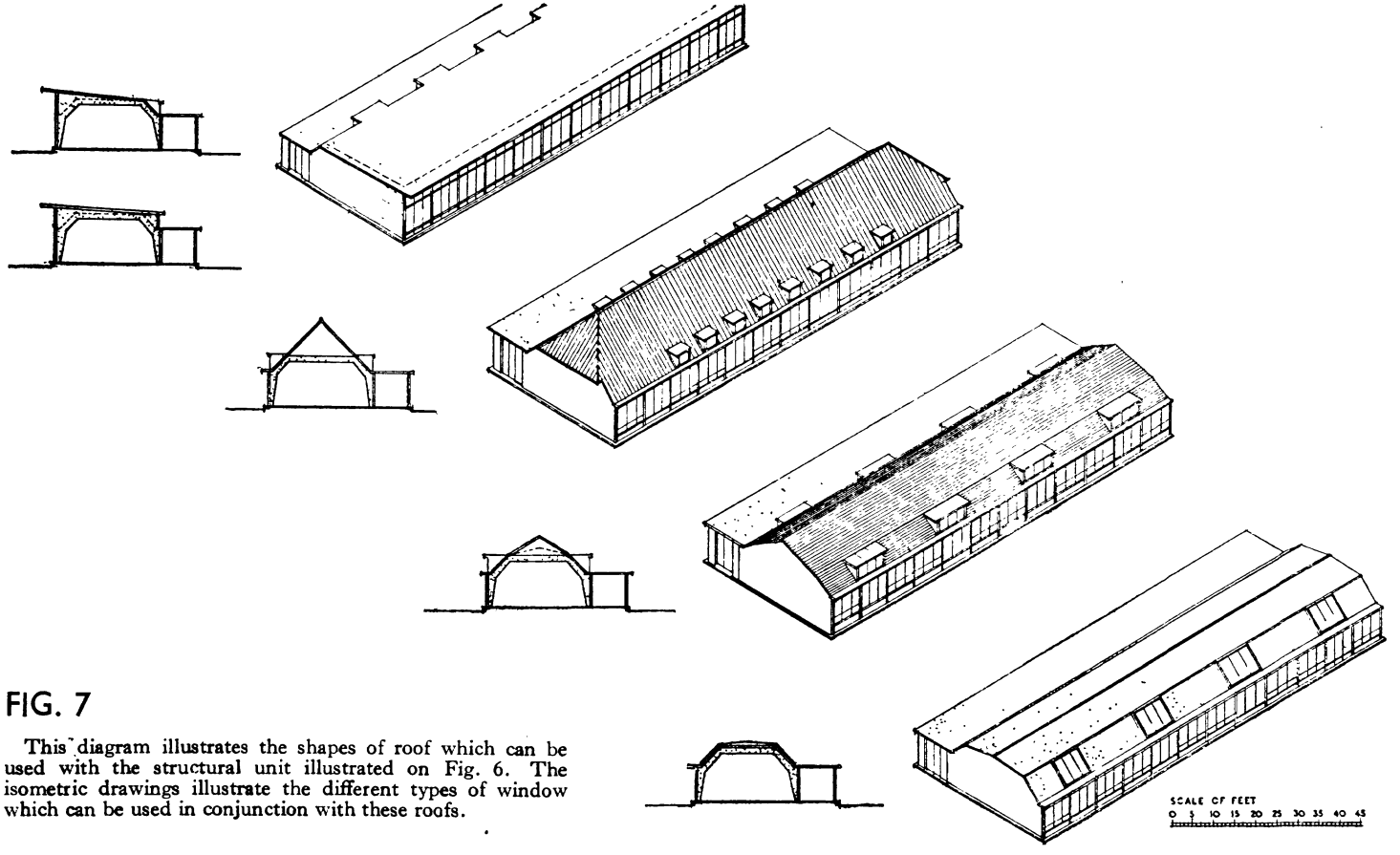


FIG. 7

This diagram illustrates the shapes of roof which can be used with the structural unit illustrated on Fig. 6. The isometric drawings illustrate the different types of window which can be used in conjunction with these roofs.

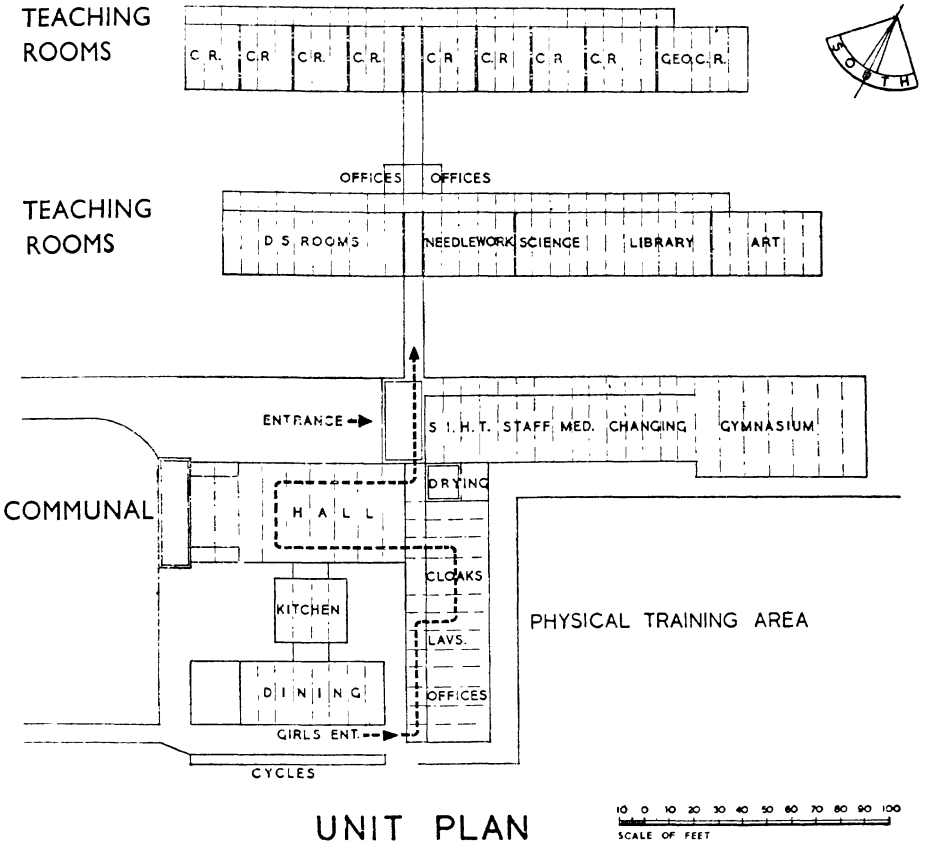
FIG. 8

This diagram shows a sample layout of a Modern School for 360 girls (3×30×4) made up of the plan units described in the general notes on Figs. 6 to 9, which are themselves built up of the appropriate number of bay units. It will be noted that the school is all on one storey. This type of structural element cannot be used for buildings of more than one storey. The plan does not show a classroom for each class, but it is easy to see how any necessary additional rooms could be added simply. The accommodation actually shown provides :

7 classrooms	24 ft.×22 ft. 6 in.	= 540 sq. ft.
1 classroom	24 ft.×30 ft.	= 720 sq. ft.
1 Geography Room	24 ft.×37 ft. 6 in.	= 900 sq. ft.
2 Domestic Subjects Rooms	24 ft.×30 ft., plus 2 stores of 7 ft. 6 in.×24 ft.	= 720 sq. ft = 180 sq. ft. each
1 Needlework Room	24 ft.×37 ft. 6 in.	= 900 sq. ft.
1 Science Room	24 ft.×37 ft. 6 in.	= 900 sq. ft.
1 Library	24 ft.×45 ft.	=1080 sq. ft.
1 Art Room	24 ft.×37 ft. 6 in.	= 900 sq. ft.
1 Hall	70 ft.×40 ft.	=2800 sq. ft. +stage
1 Gymnasium	70 ft.×40 ft.	=2800 sq. ft.
1 Dining Room	60 ft.×22 ft 6 in.	=1350 sq. ft.

plus stores, cloakrooms, changing rooms, lavatories, etc.

These are net dimensions.



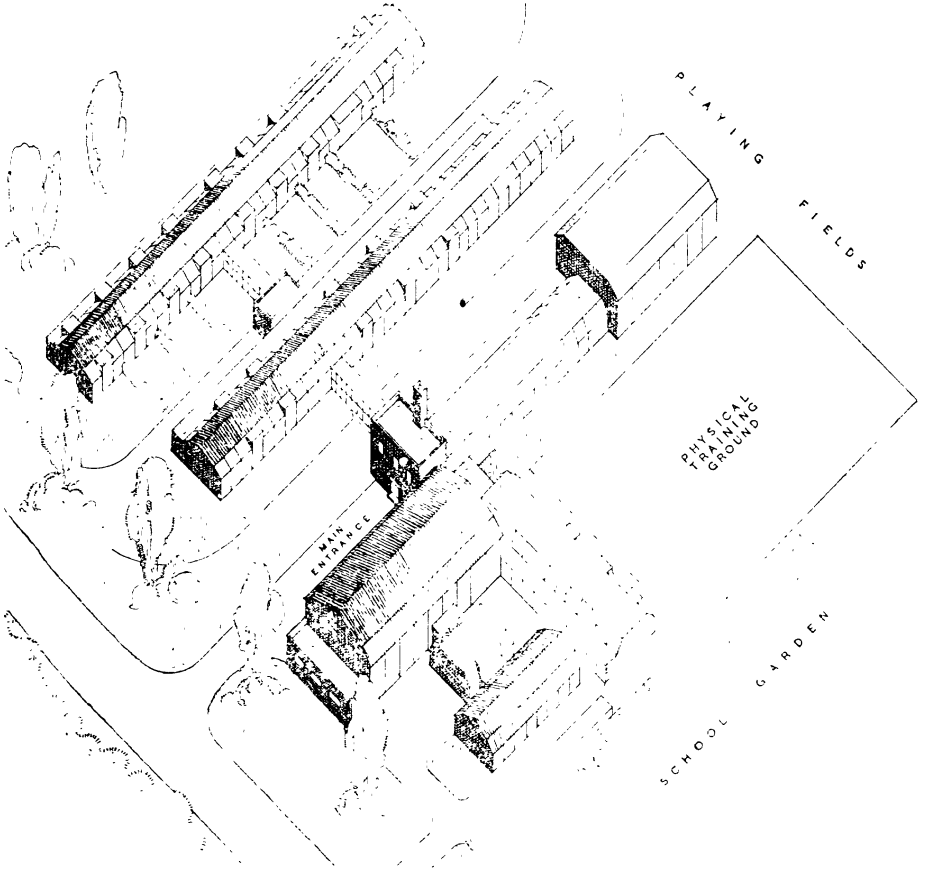


FIG. 9

This gives a bird's-eye view of the school of which the plan is shown on Fig. 8, taken from a south-south-west aspect.

GENERAL NOTES TO FIGS. 10–15

(Paragraphs 19–23)

Each of these diagrams shows a suggested detailed layout of a practical room, based on a unit dimension of 8′ 3″. The rooms have all been planned to give the commonly accepted approximate net width of 24′. Unless a separate span width for classrooms is postulated this will determine the dimension of the ordinary classroom, the other depending on the number of bay units of which it is composed. The length of the practical rooms will also be governed by the number of bay units. The respective dimensions of rooms obtainable by the adoption of different span widths and bay unit lengths can be seen in Appendix II.

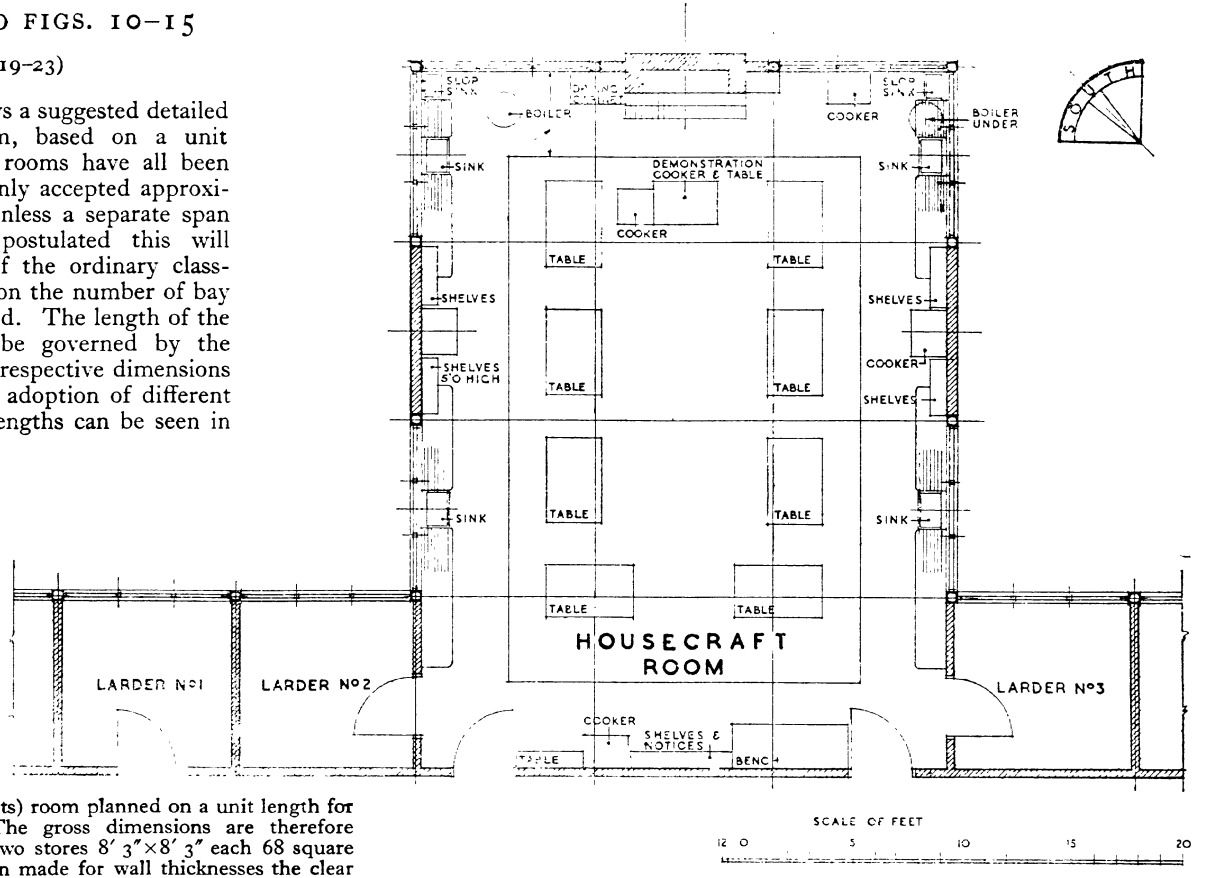
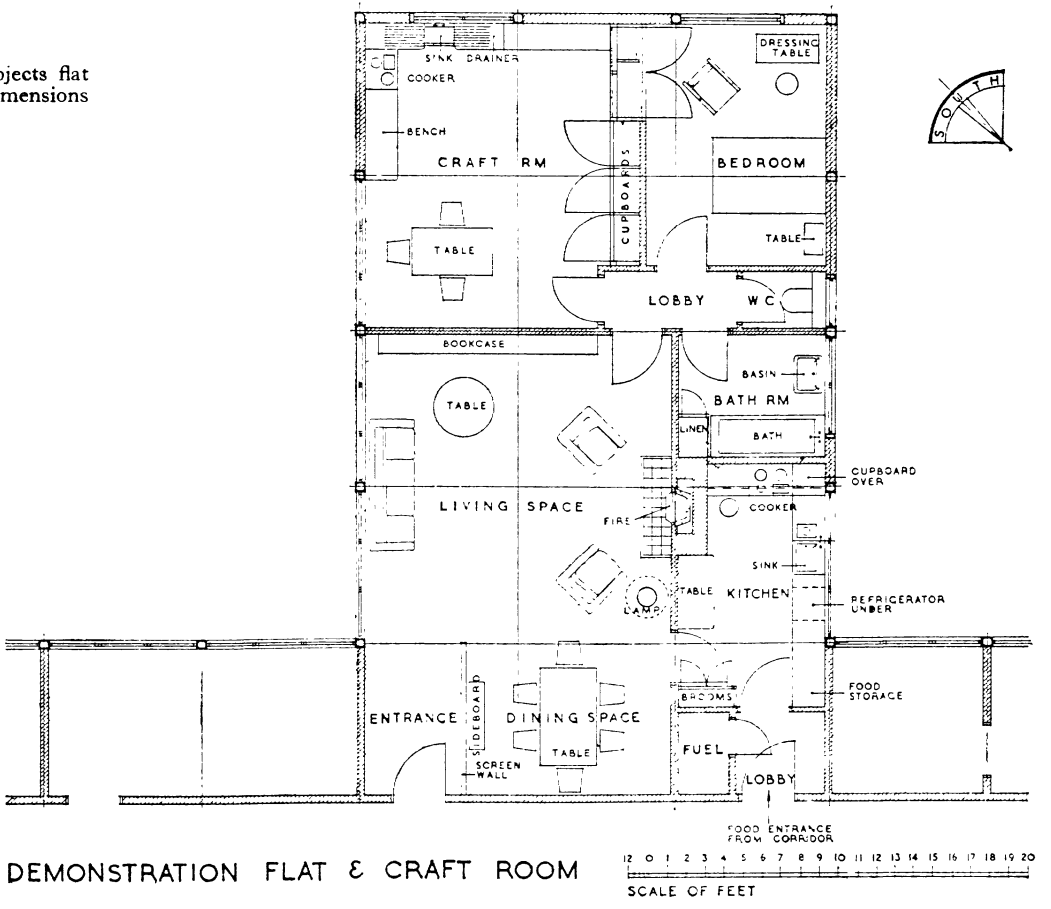


FIG. 10

Housecraft (Domestic Subjects) room planned on a unit length for each dimension of 8′ 3″. The gross dimensions are therefore 24′ 9″×33′=816 square feet+two stores 8′ 3″×8′ 3″ each 68 square feet. When allowance has been made for wall thicknesses the clear span width would be about 24′.

FIG. 11

Housecraft room and Domestic Subjects flat planned on the same basis. The gross dimensions are 24′ 9″×41′ 3″.



DEMONSTRATION FLAT & CRAFT ROOM

FIG. 12

Needlework room. Gross dimensions 24′ 9″ × 41′ 3″.

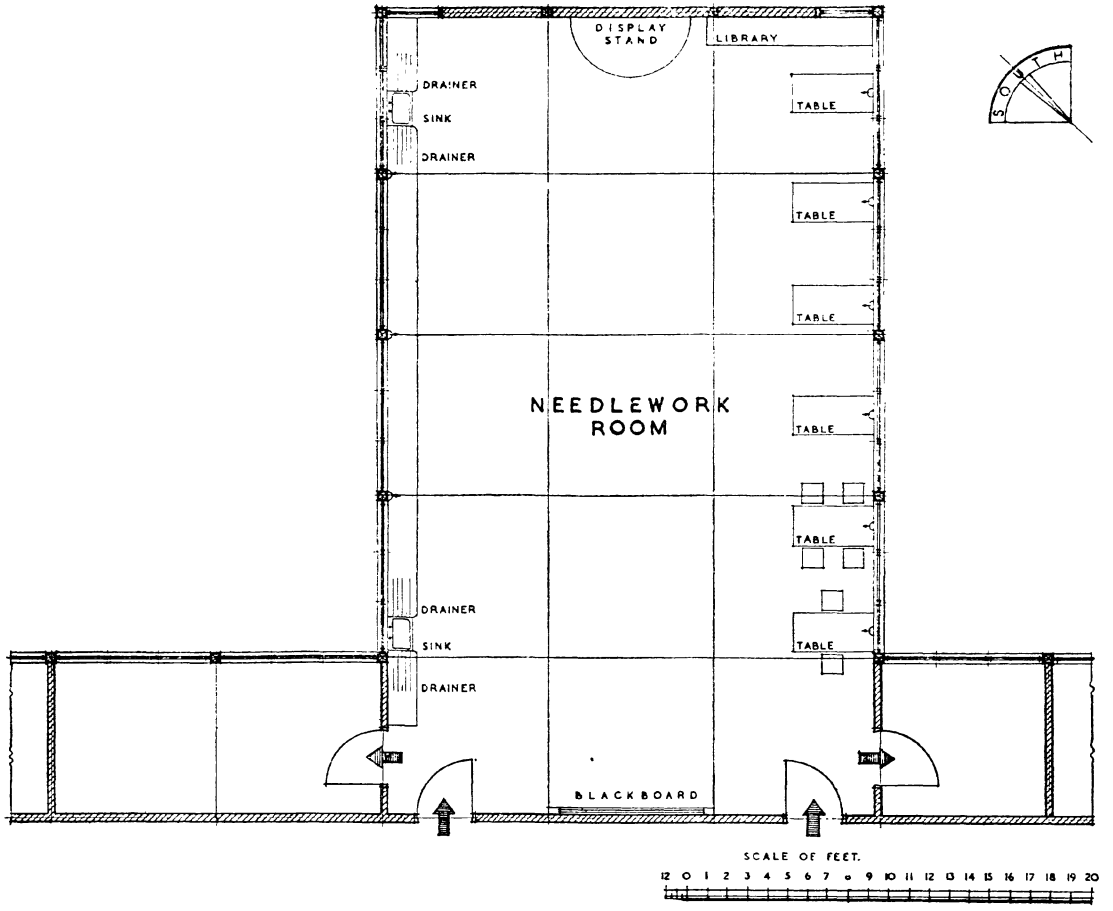


FIG. 13. See also Fig. 14 overleaf.

Science Laboratory. Gross dimensions 24′ 9″×41′ 3″+two stores, one of 136 square feet and the other of 68 square feet.

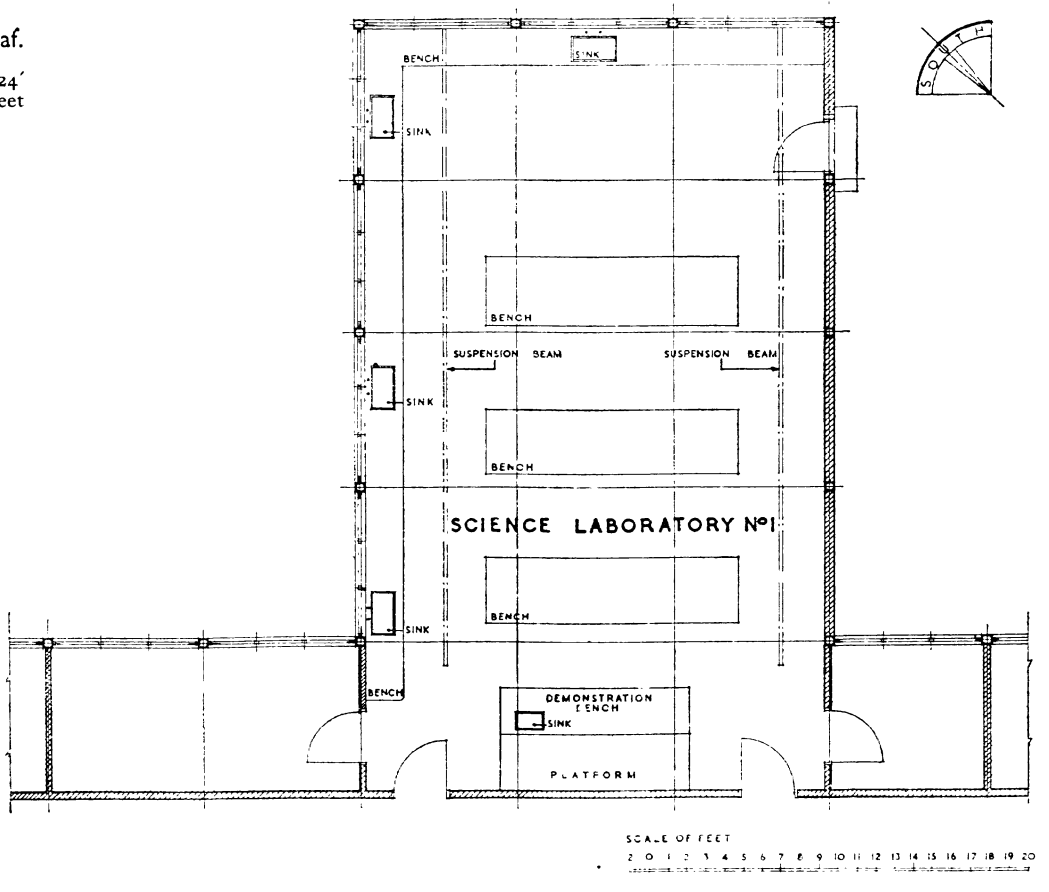


FIG. 14. See also Fig. 13 overleaf.

Alternative layout for Science Laboratory, dimensions as in Fig. 13.

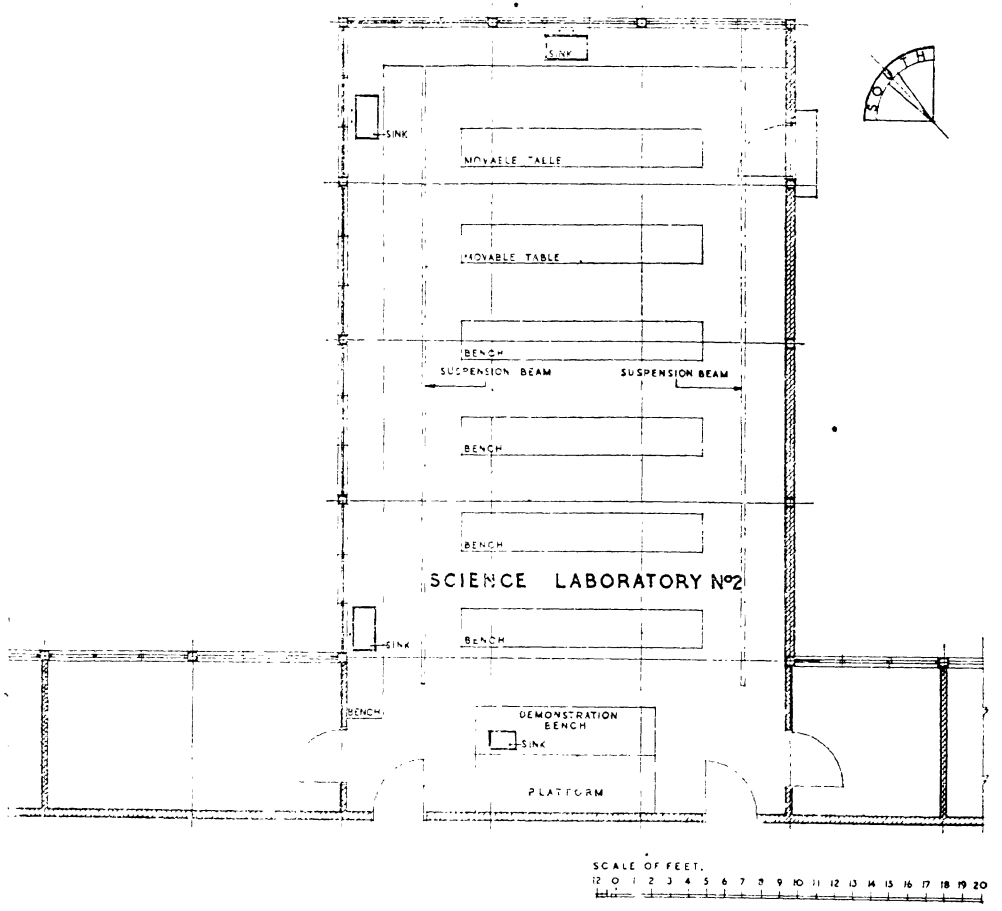
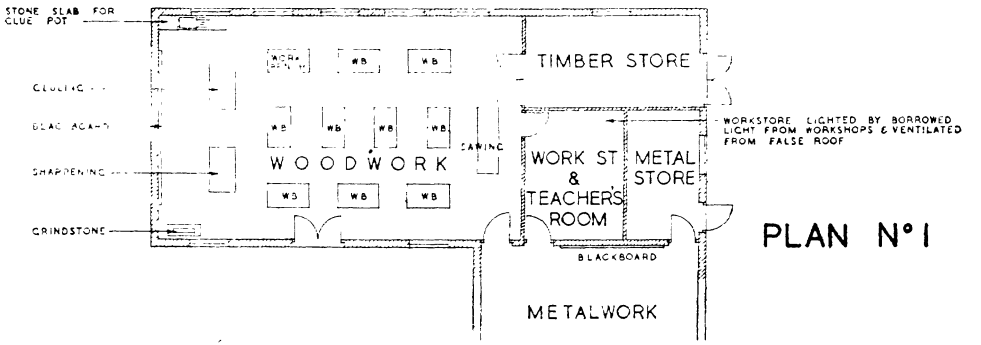
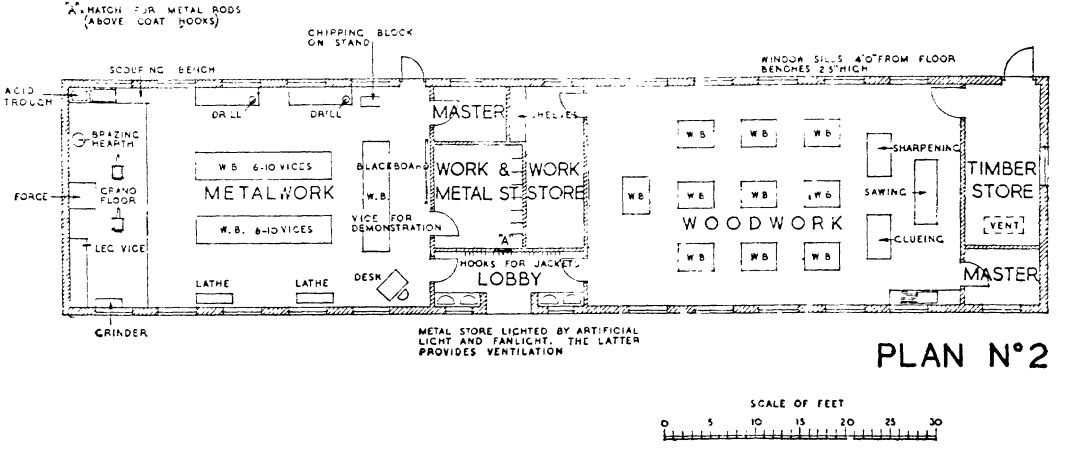


FIG. 15

Woodwork Room and Metalwork Room+stores. These are planned to actual dimensions of 40′×24′+additional units incorporating stores, master's room, etc., of overall dimensions 24′×16′. If these are taken to be net dimensions, it will be seen how closely they approximate to those resulting from the use of the 8′ 3″ unit dimension, and the same layout of equipment would probably be suitable in both cases.





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The following attended meetings of the Committee as assessors:—
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TERMS OF REFERENCE

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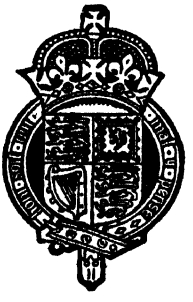
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PLASTICS

BY

A COMMITTEE CONVENED BY

THE BRITISH PLASTICS FEDERATION



LONDON: 1944

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The series of Reports being published under the title of Post-War Building Studies owes its origin to a desire expressed by professional and other institutions connected with the building and civil engineering industries to assist and support the Ministry of Works in regard to post-war plans. During the latter part of 1941 the then Minister, in order to take advantage of these offers of assistance which he was receiving from all quarters, encouraged the establishment of a series of Committees to investigate and report on the major problems which were likely to affect peace-time building. He also offered, on behalf of the Ministry, to provide the necessary staff and organisation to co-ordinate the various inquiries, in such a way as to avoid duplication of effort and to secure so far as possible uniform direction and policy.

A full list of the Reports which are being issued is given on the back page of the cover.

The Committees were either appointed by a Government Department or convened by a professional institution, a research association or a trade federation, as seemed most appropriate in each case; they were so constituted as to ensure that the Reports contain the considered views of experts and others closely concerned with the subject. The Minister gratefully acknowledges the work of the Committees and the valuable assistance given both by the various convening bodies and by the individual members. The Reports are not official publications in the sense that the Government as such is responsible for or necessarily accepts the views expressed, but their contents are authoritative and cannot but be of great value to all concerned with preparations for building after the war.

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BRITISH PLASTICS FEDERATION

THE PLASTICS COMMITTEE

To The Right Honourable Lord Portal, d.s.o., m.v.o., Minister of Works.

MY LORD, The British Plastics Federation, through its Post-War Planning Committee, made an offer to Lord Reith of Stonehaven, then Minister of Works and Buildings, to assist him in an advisory capacity; it was invited to convene a Study Committee for that purpose. We, the Committee, were convened by the Federation in December 1941 in response to his invitation.

Our study was to be part of a scheme inaugurated by Lord Reith with the object of securing a comprehensive and co-ordinated review of building technique for the guidance of those who would be responsible for the direction and organisation of building after the war.

We were charged with that part of the general scheme which relates to the application of plastics to the building industry, and our terms of reference were:

> "To consider present practice and new proposals in the application of plastics to heating and ventilating, lighting, plumbing, electrical, gas, and mechanical installations, painting, internal and external furnishing, building construction, and any other applications which may suggest themselves.
>
> "To make recommendations for practice in post-war building; to make such recommendations for further research as may arise after these studies."

We were asked to consider the problem in terms of the immediate post-war period, and of a longer period commencing about five years after the cessation of hostilities.

In view of the ramifications of the plastics industry, it was decided to set up a sub-committee to collect and collate relevant information on the following seven groups of materials:

Group 1: Moulded Plastics

Investigator: Mr. C. S. Dingley, of Streetly Manufacturing Co., Ltd., co-operating with Mr. H. Bridge, of Thomas De La Rue and Co., Ltd.

Group 2: Laminated Plastics

Investigator: Mr. A. E. Skan, of Ellison Insulations, Ltd., co-operating with Mr. A. W. Sherwood, of Bakelite, Ltd.

Group 3: Transparent and Opaque Sheeting, other than Laminated Plastics Sheet

Investigator: Mr. T. L. Birrell, of B.X. Plastics, Ltd., co-operating with Mr. W. M. C. Norie, of I.C.I. (Plastics), Ltd.

Group 4: Resinous Materials, Plastics, Cements, and Adhesives

Investigator: Mr. H. V. Potter, assisted by Mr. A. Lowe, of Bakelite, Ltd.

Group 5: Extruded Plastics

Investigator: Mr. W. M. C. Norie, of I.C.I. (Plastics), Ltd., co-operating with Mr. T. L. Birrell, of B.X. Plastics, Ltd.

GROUP 6: RESIN BONDED SHEETS, INCLUDING PLYWOOD, COMPOSITE BOARDS, AND SIMILAR MATERIALS, OTHER THAN LAMINATED PLASTICS

Investigators: Mr. R. J. Schaffer and Mr. R. A. G. Knight, of the Department of Scientific and Industrial Research.

GROUP 7: MISCELLANEOUS, INCLUDING EXPANDED PLASTICS

Investigator: Mr. T. L. Birrell, of B.X. Plastics, Ltd.

In the present Report all the available information on the use of plastics in building has been surveyed. To avoid misunderstanding, we have felt it desirable to refer to the sources from which plastics are derived and the processes through which they pass to reach the builder's hands. The treatment does not purport to be exhaustive.

We now beg leave to present our Report, which, it is hoped, will be helpful to you and to the architects and all others concerned with building after the war.

We gratefully acknowledge the help that was so freely given by colleagues and associates of the investigators, and by the staff of the British Plastics Federation.

We have the honour to be, my Lord,

Your obedient servants,

H. V. POTTER,

Chairman, on behalf of the Plastics Committee

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PLASTICS

A REPORT BY A COMMITTEE CONVENED BY THE
BRITISH PLASTICS FEDERATION

INTRODUCTION

1. DEFINITION OF PLASTICS. The term "plastics" is applied to a group of materials which, though stable in use at normal temperatures, are plastic at some stage in their manufacture and can be shaped by the application of heat and pressure.

2. Plastics are organic materials, mainly synthetic, but they include semi-synthetic materials derived from cellulose and casein, and also certain materials incorporating bitumen and shellac. Rubber, though organic and falling within the definition given, is, by common consent, not considered to be a "plastic," though synthetic, rubber-like materials are. Inorganic plastic materials, such as glass, ceramics, and Portland cement, are likewise excluded.

3. THERMOPLASTIC AND THERMOSETTING PLASTICS. Plastics fall into two broad classes, thermoplastic and thermosetting. Thermoplastics soften on heating and harden on cooling, and this softening on heating can be repeated as often as may be desired. Thermosetting plastics, on the other hand, can be prepared in a form in which they are initially thermoplastic, in which condition they can be moulded under appropriate conditions of temperature and pressure; further heating at quite moderate temperatures (260–350° F.) causes them to set permanently. They cannot again be softened by heating, but, being organic materials, they char at a temperature of about 650° F

4. MERITS AND LIMITATIONS. Although plastics have taken the place of metals, wood, and ceramics in many articles in common use, and quite properly can be looked upon as alternative materials, they are not to be regarded as substitutes in any derogatory sense, but rather as materials having certain properties by virtue of which they are capable of fulfilling particular functions or meeting particular demands. That is not to say that plastics are suitable for all purposes, or that a plastic can always be found to suit a particular purpose. Like all other materials, they have their merits and their limitations. Their uses should be chosen accordingly.

5. Among their merits are their good dielectric properties, their wide range of colour, and their clean finish, which, for indoor use at all events, is not subject to corrosion and does not need protection with paint or lacquer. Plastics lend themselves to mass production, and, being manufactured products subject to technical control throughout the various processes, can be produced in a degree of uniformity difficult to attain in a natural material. To all intents and purposes they leave the machine in a condition in which they are ready for use; polishing and finishing operations are not always required. The equipment is expensive, and the cost must necessarily be spread over a large number of articles if the process is to be economic. A valuable feature of plastics is their adaptability. They lend themselves to a variety of manufacturing operations, yielding products that cover a wide range of uses.

6. Plastics are not suitable for use at high temperatures; some can be used up to 200° F. and others up to 450° F. Some plastics are not suitable for use out of doors, though materials of improved durability have become available and further improvement can be expected. Again, some plastics tend to creep under sustained loads, and some are subject to a brittle type of fracture with no pronounced yield-point. These features impose certain limitations on their use as building materials.

7. HISTORICAL DEVELOPMENT. Although bitumen has been known and used from ancient times, and some of the materials employed have long been known to chemistry, the plastics industry may be said to date from the discovery and application in 1865 of a method of plasticising cellulose nitrate. Since then there has been a phenomenal development of new materials, the result of chemical achievement, and a continual adaptation of the processes of manufacture, leading to the production of plastics in new forms and with new uses. A large number of the plastics in use today have been introduced within the past twenty years, many within the last two or three years. Objects are now being moulded in sizes that would have been considered quite impracticable a short while ago. The pace of development makes it very difficult to forecast future trends or to say categorically that plastics are unsuitable for this purpose or for that; today's outlook may be quite changed by the advent of a new material or new process.

8. SPECIFICATIONS AND HALL-MARK OF QUALITY. Some applications of plastics to buildings are already well established, and materials have been manufactured to fairly definite standards of material and design. Sometimes, however, plastics mouldings for building and other uses have been designed to a price rather than with proper regard to functional requirements, and have proved unsatisfactory in service. The standards of the materials used are maintained by specification (see Appendix III). Design is much more difficult to control, and design plays a large part in determining the efficiency of a moulded plastic. It was with the intention of ensuring the production of well-designed, efficient products that the British Plastics Federation in collaboration with the British Standards Institution took steps in 1938–9 to initiate a hall-mark scheme. Completion of this scheme has been delayed by war conditions, but is now being reconsidered.

9. CONSULTATION BETWEEN BUILDING AND PLASTICS INDUSTRIES. Besides the established uses of plastics in building, there are others, notably for plumbing, which have yet to prove their practical worth. Other applications for which plastics would be suitable, such as the manufacture of composite wall linings of good thermal insulation value and pleasing appearance, have yet to be studied in detail. Guidance from the building industry on the properties and sizes desired in a material of this kind would greatly assist the plastics industry in formulating its plans. Where a new proposal involves no more than the fabrication of materials already in production or the simple modification of existing processes, experiments and trials can be undertaken without much difficulty, providing the materials and plant can be released for the purpose. But where a new proposal involves the production of a moulded article—a window frame, for instance—the manufacture of prototypes for trial cannot be lightly embarked upon. The moulds are expensive. Their design, the choice of moulding material, and every aspect bearing on the production of a satisfactory article at a reasonable cost must first be given the most careful consideration. The cost of moulded plastics cannot be discussed in general terms because so much depends on the numbers over which the cost of the moulds can be distributed. Some articles can be produced in plastics with greater efficiency and at less cost than in other materials. Some may be more expensive. In the post-war period choice may need to be guided by the relative availability of the various alternatives, irrespective of their relative cost.

10. POST-WAR PRODUCTION OF PLASTICS will depend on supplies of materials and on plant capacity. And it must be borne in mind that the output of plastics materials will be limited by the availability of raw materials, and that, in some cases, raw materials are limited by factors outside the control of the industry; many of them depend on products of the chemical industry. While there has been an expansion in production to meet demands for war equipment, an expansion which, incidentally, has been accompanied in some instances by notable reductions in the cost of manufacture, plastics are not produced in such large quantities as to compare with the basic industries in building, such as steel, cement, and brick. The total production of plastics in Great Britain represents but a small fraction of the volume of building materials likely to be required in the immediate post-war period. Not all this production will be of materials suitable for application to building use, and some of the post-war supplies will be needed for other purposes. While there will undoubtedly be wide scope for the use of plastics in the post-war programme, it will be important to select applications that will make the best use of the plant and materials available and give the greatest satisfaction in service.

PART I. MATERIALS, PROCESSES OF MANUFACTURE, AND PROPERTIES

11. This section presents a simplified technical survey of plastics for those who may be interested.

1. MATERIALS

12. DERIVATION OF PLASTICS. A popular conception that plastics are made from milk applies to one type only, namely, casein plastics, which are made from rennet casein, a by-product of milk manufacturing processes.

13. Another conception—not uncommonly held—that plastics are derived from coal, air, water and limestone is true of most plastics other than casein and cellulose plastics, but is only a half-truth because it fails to convey any impression of the complexity of the processes involved, and its implications are misleading. Coal (or petroleum or natural gas), air, water and limestone, and cellulose (obtained from cotton linters or wood) are, indeed, the principal basic raw materials of the plastics industry, but the development of plastics is a chemical achievement. It requires complex chemical processes involving the use of elaborate and costly plant to convert the basic materials into the forms in which they are used. In other words, the plastics industry depends on the chemical industry and on chemical engineering for many of its raw materials and the potential volume of production depends on the supply of these intermediates.

14. To trace back to their origin the materials used in the manufacture of plastics reveals a fascinating story. Its complexity can be gathered from the Chart of Chief Plastics Materials which will be found on the two centre pages of the Report. To name but a few essential constituents, phenol, cresol, benzene (which can be converted into phenol) and coke are obtained from coal by distillation. Coke, air and water supply the gases required for the synthesis of methyl alcohol and ammonia. Formaldehyde, once made exclusively from wood alcohol, is now made from synthetic methyl alcohol. Urea is made from carbon dioxide (derived from coal) and synthetic ammonia. Phenol (and cresol), urea and formaldehyde form the basic materials for the phenol-formaldehyde and urea-formaldehyde groups of plastics. (See table "Classification of Plastics" below.) Acetylene (the basis of the vinyl group) is made from calcium carbide prepared by heating limestone and coke to a high temperature in an electric furnace.

15. It will be apparent, even from this very brief survey, which refers to no more than three types of plastics and takes no account of the many accessory chemical compounds used as solvents, plasticisers, colouring materials and so on, how much the industry depends on chemical processes for its supplies. It will also be appreciated that coal distillation provides much of the raw material. Great Britain is favourably placed for coal, but a large proportion of the potentially available chemical supplies is at present being wasted. More efficient methods would make these available for industrial use. This country is less favourably placed for supplies for certain other groups of plastics. The lag in development of vinyl plastics can be attributed to the lack of cheap supplies of electricity to produce calcium carbide. Ethylene, which is assuming increasing importance in the plastics field, is principally derived from petroleum and natural gas. Importation of crude petroleum to be refined in this country would supply some of the needs.

16. CLASSIFICATION OF PLASTICS. Mention has already been made of a few types of plastics. A table showing the classification of plastics, from which, for simplicity, types of subsidiary importance have been omitted, is given below. Plastics of the synthetic group are commonly termed synthetic resins. Phenol-formaldehyde, urea-formaldehyde, glycerol-phthalic anhydride and aniline-formaldehyde plastics are thermosetting. Melamine-formaldehyde plastics can be made either thermoplastic or thermosetting. The remainder are thermoplastic.

CLASSIFICATION OF PLASTICS

Natural	*Semi-synthetic*	*Synthetic*
Shellac.	Casein.	Phenol-formaldehyde.
Bitumen.	Cellulose derivatives :	Urea-formaldehyde.
	Cellulose nitrate.	Aniline-formaldehyde.
	Cellulose acetate.	Melamine-formaldehyde.
	Cellulose butyrate.	Glycerol-phthalic anhydride.
	Cellulose acetate-butyrate.	Polyamides—*e.g.* Nylon.
	Benzyl cellulose.	Vinyl derivatives :
	Ethyl cellulose.	Polyvinyl alcohol.
	Methyl cellulose.	Polyvinyl acetate.
		Polyvinyl chloride.
		Polyvinyl chloride-acetate.
		Polyvinyl acetals :
		Polyvinyl formal.
		Polyvinyl acetal.
		Polyvinyl butyral.
		Polystyrene.
		Polyethylene.
		Acrylic esters—*e.g.* Methyl methacrylate.
		Polyvinylidene chloride.

17. The following paragraph is included to explain some of the terms used in this Report and why some materials are thermosetting and others thermoplastic.

18. MOLECULAR STRUCTURE. Plastics are formed by the linking together of molecules of chemical raw material to form more complex molecules of plastics having either a chain-like structure or a net-like structure with linkages in three dimensions. Those with chain-like molecules are thermoplastic. Those capable of forming net-like molecules are thermosetting. Where cellulose is the starting material, the cellulose itself forms the long chain-like molecule. Among the synthetic plastics the complex molecules are produced by a combination of simple molecules (monomers), the process being known as "polymerisation" (or "condensation" if the process involves the elimination of water), and the products as "polymers." Phenol and urea combine with formaldehyde (with the elimination of water) to form chain-like molecules, and in this form the product is thermoplastic. Further heating causes cross linkage to occur and the product becomes infusible. On the other hand, monomers of styrene, vinyl chloride, methyl methacrylate and so on unite under suitable conditions to form chain-like molecules of polystyrene, polyvinyl chloride and polymethyl methacrylate respectively, but, having no suitably disposed reactive groups within the molecule to permit of cross linkage, the polymerised material is permanently thermoplastic. Copolymers are made by polymerising a mixture of two or more monomers, such as vinyl chloride and vinyl acetate.

19. The wide field of utilisation of thermosetting plastics depends to a considerable degree on the fact that the chemical changes involved occur in stages, that in the earlier stages the products are thermoplastic, and that in this form they may be either liquid or solid at the ordinary temperature. The further stage to the thermoset condition is usually brought about by heating—hence the term thermosetting plastics—but it can also be brought about at air temperature by the addition of hardening agents or accelerators. Advantage is taken of this property in the preparation of cold-setting synthetic glues. Another valuable feature of the intermediate thermoplastic stage is that the materials are soluble in alcohol and certain other organic solvents and can form solutions or emulsions with water. Their solubility allows them to be used in paints, lacquers and impregnating varnishes. The finished products are insoluble in all ordinary solvents.

20. VARIETIES OF PLASTICS. Among the plastics named in the "Classification of Plastics" table above, there are literally hundreds of different varieties, produced by variation in the choice of materials or in the making conditions, or by combining one type with another, or by variation in the accessory materials used as fillers and plasticisers. These again are used in a number of different ways to produce a variety of products having a wide range of physical and mechanical properties and with all manner of practical uses. One illustration will suffice. Polyvinyl chloride can be made in the form of rigid sheets which may be either clear and transparent or opaque. It can be compounded to form a rubber-like product in any required degree of flexibility, or made as a solution for use as an applied finish. It can be used as a textile fibre and woven into fabric. Other illustrations of the adaptability of plastics will appear in discussing the methods of manufacture and uses.

2. PROCESSES OF MANUFACTURE AND PROPERTIES

21. The raw materials used in the plastics industry are products of the chemical industry. Their manufacture into utilitarian articles involves the heavy engineering industry which supplies moulds, hydraulic plant and other machinery. The methods will be described to illustrate the production of the types available for use in the building industry rather than to present a comprehensive and detailed picture of the operations involved. All the processes take advantage of the mouldability of plastics, so that all are in effect moulding processes. It is convenient for present purposes to treat separately the production of what are described as "moulded goods," which are usually made from moulding materials, and are produced in their completed form ready for fixing, and production in the form of sheets or continuous strips, which require fabrication when they are being fixed in the building. Even so, the processes and materials used in the production of sheet and strip materials also lend themselves to the production of moulded articles and moulding materials are used to make products in continuous lengths. The versatility of plastics precludes a strictly logical presentation.

"MOULDED GOODS"

22. "Moulded Goods" are made from moulding materials which may be thermosetting or thermoplastic. Those of the thermosetting type usually incorporate a reinforcing medium which, though often described as a filler, is in no sense a diluent or extender, but an essential constituent which largely determines the properties of the finished product. Some moulding materials are reinforced with wood flour. Heat-resistant grades are reinforced with asbestos fibre and shock-resistant grades with cotton flock or shredded canvas. *British Standard* 771–1938 covers five different grades of thermosetting moulding powder. Thermoplastic

moulding powders are compounded with colouring materials, and plasticisers are gauged according to the requirements for the finished article.

23. METHODS OF PRODUCING MOULDINGS. In compression moulding the requisite weight of material is loaded into a heated steel mould and the mould closed. The material softens and flows under the heat and pressure applied.

24. In the manufacture of thermosetting moulding powders the object is to carry the polymerisation of the resin to such a stage that it still retains sufficient thermoplasticity to enable it to flow at the mould temperature, but yet requires no more than a limited time to harden or "cure" at that temperature. The quality of the product and the speed of production depend on the correct balance between these properties which are very carefully controlled in the course of manufacture. Thermosetting mouldings are withdrawn from the mould while it is still hot.

25. Thermoplastic mouldings have to be cooled before they are withdrawn. They are commonly made by the injection moulding process, in which the heat-softened plastic is injected, under pressure, into a cold mould, or they are made from sheets which are heat-softened before being pressed in a heated die which is then cooled by water. A recent development in technique is the use of wooden moulds for shaping articles made from thermoplastic sheets. The sheets are heated on a hot plate and pressed into the moulds. The resulting moulding is only allowed to cool long enough to be rigid and is withdrawn while quite warm. The injection principle has been applied to thermosetting moulding powders and is sometimes known as "transfer" moulding.

26. The presses used in compression and injection moulding can be made fully automatic in operation. Mouldings are completed in one operation, and, beyond removal of the "flash," machining or finishing operations are not usually required.

27. Reference must also be made to the cold moulding of bitumen plastics. Bitumen (or pitch) is compounded with asbestos, diatomaceous earth and other fillers. The mouldings, produced in cold moulds, are subsequently cured by heating in ovens. Water tanks and cisterns, fuse boxes, switches, battery boxes and telephone insulators are made from bitumen plastics. These are all brown or black in colour. Bitumen plastics have good weathering properties and water resistance, and are used for electrical gear exposed to conditions of high humidity or intended to be used out of doors.

28. CAST RESINS as distinct from mouldings are produced with or without a filler to make transparent, translucent or opaque objects by a casting process. A thermosetting resin in liquid form is poured into moulds and subsequently hardened by heat. Thermoplastics can be cast in warm moulds and allowed to cool. They are machined to final shape.

29. SIZE AND RANGE OF MOULDINGS. Plastics moulding processes are being used to manufacture articles ranging in size from a switch dolly weighing a fraction of an ounce to a coffin weighing 90 lbs. Metal inserts, working parts, fixing devices or additional reinforcement can be placed in the moulds to become secured in the finished article. The wide range of moulded products applied to building uses is indicated in Appendix I.

30. CHOICE OF MATERIAL AND DESIGN OF MOULDINGS. The utility of the finished article is dependent upon making the right choice of moulding material for the particular purpose, on suiting the design to the medium in which it is to be executed, and, with thermosetting plastics, on a proper degree of "cure." The plastics industry has had wide experience in applying its materials to a host of practical uses, and responsible manufacturers have been at pains to ensure the quality and serviceability of their products.

31. It should be realised that one style of design may be more suited to the moulding process than another. It is, for instance, simpler to mould a switch cover plate and threaded ring separately than to mould a threaded switch cover. The design of the finished article needs to take full account of the process of production. Undercuts complicate the moulding operation; corners and edges need to be rounded to a suitable radius; tolerances on dimensions need adjustment according to the material to be used. In short, there should be the closest collaboration between the designer of the article and the designer of the mould.

32. PROPERTIES OF MOULDINGS. The properties of moulded thermosetting plastics depend on the type of resin used and on the character of the filler; those of thermoplastic mouldings on the amount and nature of the plasticisers with which they are compounded.

33. COLOUR OF MOULDINGS. Phenol-formaldehyde resins are themselves of an amber colour and do not lend themselves to the production of light-coloured articles, but urea-formaldehyde and other plastics mouldings can be made in white or ivory shades and in a wide range of colours, including pastel shades.

34. MOULDINGS FOR OUTDOOR CONDITIONS. Special grades of phenol-formaldehyde moulding powders give a reasonable degree of durability out of doors. Apart from these and the bitumen plastics referred to in an earlier paragraph, moulded plastics are more suitable for interior than for exterior use. It is probable that the durability can be improved by painting with suitable paints, but, so far as is known, practical trials have not yet been undertaken.

SHEET PLASTICS

35. The plastics industry provides a variety of sheet materials used in building as wall and ceiling linings, as bath and switch-board panels, as floor coverings, and in the construction of counters, tables and furniture generally. Certain types of plastics are made in the form of sheets or slabs of low thermal conductivity for use as heat-insulating materials, others as transparent or translucent glazing materials. Sheet plastics include laminated plastics, resin-bonded plywood and a range of transparent and opaque sheets of various kinds. Mention must also be made of fibreboards made from waste vegetable fibres, which, though a product of the paper-making industry rather than of the plastics industry, are of immediate interest since they have been used in combination with plastics to make composite boards for building use. The plastics technique lends itself particularly well to the manufacture of composite materials. Combinations of plywood, metal, laminated and other plastics with fibre-insulating board and with other heat-insulating materials can be produced without difficulty.

LAMINATED PLASTICS

36. METHOD OF MANUFACTURE OF LAMINATED PLASTICS. In the production of laminated plastics, sheets of paper or fabric, which may be of cotton, flax, jute or glass fibre, are impregnated with an aqueous or alcoholic solution of a thermosetting resin. For light-coloured sheets urea resins are used. These may be coloured throughout or may consist of a light-coloured facing on a phenolic resin sheet-backing. The impregnated paper or fabric is dried, cut to size, placed in stacks and cured under pressure between heated platens. The surface sheet can, if required, incorporate a printed design which becomes an integral part of the sheet. Wood veneer can be used either for surfacing or in any desired arrangement in combination with the impregnated paper or fabric to modify the properties of the product. An underlying metal sheet is commonly incorporated in laminated sheet intended for surfacing counters or table-tops. This provides a heat-conducting

layer and confers immunity from cigarette burns. Metal can also be used for the surface of the sheet to give the appearance of metal and to improve the resistance to moisture. The size of sheet is limited to the size of the press used, the maximum size at present being 8 ft. × 4 ft.

37. HOLLOW PANELS. Hollow panels with longitudinal spacing strips, intended for use as light-weight partitions, are made in one operation by wrapping the impregnated paper or fabric round suitably shaped and disposed metal bars. Hollow panels of "egg-box" structure can also be made.

38. TUBES, RODS AND BARS. Tubes, rods and bars are made by winding the impregnated paper or fabric on mandrels, and pressing and curing between heated rollers or in heated moulds.

39. MOULDED SHAPES. The laminating technique can be used to produce simple moulded shapes in hydraulic presses. Large articles of more complicated shape can be made by the rubber-bag process described in a following paragraph.

40. PROPERTIES OF LAMINATED PLASTICS. Laminated plastics are generally much stronger than mouldings made from powder. They can be supplied in matt, satin matt or glossy finishes. Satin matt or matt surfaces may be preferred because the surface is more easily restored in the event of accidental damage. In sheets incorporating a fabric finish a textured appearance is obtainable without losing the advantage of a smooth surface.

41. The range of colours available is perhaps unequalled among building materials, and further variations are obtainable by the use of patterned or textured surfaces. The surfaces are hygienic and easily cleaned. They are durable even when subjected to rough usage, and for that reason laminated plastics have been much used as kicking-plates. Laminated plastics have hitherto found their widest application in hospitals, ships and public buildings where their hygienic properties and wearing qualities are particularly advantageous.

42. Laminated plastics can be cut and machined to shape in a similar manner to wood and metal. Whilst their production requires heavy and expensive plant, their fabrication is not necessarily a mass-production process.

RESIN-BONDED PLYWOOD AND IMPROVED WOOD

43. METHOD OF MANUFACTURE OF RESIN-BONDED PLYWOOD. Resin-bonded plywood is made by gluing wood veneers with synthetic resin glues based usually on phenol-formaldehyde or urea-formaldehyde resins. The processes employed are either the "film-glue" method, in which sheets of thin paper, impregnated with a resin varnish and dried, are interleaved with the veneers and the pack then pressed and cured between heated platens; or alternatively, the ordinary glue-spreading method, in which the liquid glue is spread on the veneers and caused to set under pressure. In the latter process both hot- and cold-setting glues are used. In cold-gluing processes the hardener can be added to the glue before use or glue and hardener can be applied separately to opposite faces of the veneer. In this way the risk of premature setting of the glue is avoided.

44. SIZES. Plywood can be prepared from a very wide range of timber species and is available in thicknesses ranging from less than $\frac{1}{32}$ in. upwards and in sizes up to 8 ft. × 28 ft., though the general run of stocks is about 5 ft. × 4 ft. or 5 ft. × 5 ft. However, the technique of making scarfed joints has advanced so much that plywood is virtually obtainable in any size that may be needed.

45. Besides flat sheets, resin-bonded plywood can be manufactured in the form of circular or rectangular tubes or in channel or other sections suitable for constructional purposes.

46. The veneers can also be moulded over suitable forms to produce shapes of simple or compound curvature. Shaped wood and hollow panel structures represent new departures which extend the range of uses.

47. "RUBBER-BAG" MOULDING PROCESS. Within the last two years a process known as the autoclave or rubber-bag process has been perfected, by means of which moulded articles of a size formerly impracticable can now be produced without difficulty. In this process the glued veneers are suitably cut and disposed over the mould, which may be of wood or metal. The whole is then loaded into an autoclave (pressure tank), the temperature of which can be raised to set the glue. Within the autoclave, the veneers are pressed uniformly to the shape of the mould by pressure exerted by the use of a rubber bag or sheet. There are various ways of doing this. The mould and veneers may be enclosed in a rubber bag which is deflated. Steam and air are then admitted to the sealed autoclave to give the required temperature and pressure. Alternatively, the moulding may be covered with a sheet of rubber which is fixed so as to make an airtight connection with the floor of the autoclave and is provided with an outlet to allow the air to be withdrawn from beneath it. Another method is to inflate a rubber bag between the moulding and the walls of the autoclave. Hollow mouldings can be made by inflating the bag within the mould. The pressure used is ordinarily about 20 lb. per sq. in., though it may be higher if need be, and the temperature about 240° F. according to the type of glue used. Complete fuselage units and other parts for aircraft and boats are made in this way. Building components, staircases, for example, in moulded plywood, complete and ready for fixing, would seem to be within the capabilities of the process and to merit investigation.

48. PROPERTIES OF RESIN-BONDED PLYWOOD. The development of synthetic resin glues, which are highly resistant to water and immune from attack by micro-organisms, has greatly extended the field of application for plywood, the utility of which is now determined, not by the durability of the glue line, as was formerly the case, but by the resistance to decay of the wood itself. As the wood can be treated with preservatives to prevent attack by fungi, plywood can now be made which is highly durable under the worst conditions of use.

49. But it must not be assumed that the casein and animal glues are out-dated and will necessarily be superseded by wholly synthetic adhesives. Within their own field, casein and animal glues are excellent and can be used with confidence.

50. Plywood offers no difficulty in fabrication. It can be stained or painted or can be covered with decorative veneer. It can be obtained with metal facing. Combinations of wood veneer with paper-base or fabric-base plastics are being developed.

51. IMPROVED WOOD. There are other highly specialised laminated materials, known as "improved wood," which are built up in much the same way as resin-bonded plywood. These can be made to high strength and moisture-resisting specifications, and are in current use in the aircraft and electrical industries.

RESIN-BONDED SHEETS OTHER THAN LAMINATED PLASTICS

52. RESIN BOARDS MADE BY A PREMIXING PROCESS. Resin-bonded sheets are made by a premixing process in which synthetic resin emulsions are added to a rag pulp. The resin precipitates on the fibre and the pulp is run off on a paper-making machine and dried. The sheet so produced is cut to size, stacked to form the requisite thickness and is cured under heat and pressure. The boards so produced are similar in outward appearance to laminated plastics sheet. This type of process can also be used to make simple moulded shapes.

53. BOARDS MADE FROM WOOD WASTE, ASBESTOS WASTE AND FLAX SHIVES. In attempts to turn to practical use the large quantities of sawdust, wood chips and shavings that are now available, efforts have been made in several quarters to make boards for building purposes, using synthetic resins as binding agents. Phenolic and urea resins have been used, and some firms have experimented with other binders. The screened waste is mixed with the binder, moulded into sheets and cured under appropriate conditions. Asbestos waste and flax shives have been used in a similar manner. The boards can be made in a variety of surface textures or they can be faced with wood veneers or with fabric.

54. Development has been hampered by shortage of pressing facilities and by restrictions in the supply of resin for the purpose, but some of the products have been quite promising, and further development may be expected when conditions are less abnormal. In ordinary circumstances the disposal of sawdust and wood waste has not presented any serious problem in this country, but the opinion is expressed by firms interested in the project that under peace-time conditions production of wood-waste boards is unlikely to lapse for lack of material.

55. FIBREBOARDS, manufactured from waste vegetable fibre (wood, bagasse, liquorice root, maize stalks, waste-paper and the like) by a felting process, are a product of the paper-making industry and are not as a rule resin-bonded. Some manufacturers add small quantities of synthetic resins to serve as binding agents; others depend solely on the lignin and resinous constituents present in the raw material. Fibreboards are referred to here because they can be used in association with plastics sheet so as to make composite boards, with mutual advantage to each. Fibreboard may be homogeneous or laminated. Homogeneous fibreboards are made in two forms: a low-density form commonly known as "insulating board," and a denser form known, according to the grade, as "medium hardboard," "hardboard" or "superhardboard."

56. The waste cellulose material used is reduced to a pulp which is run off on a paper-making machine to form a thick mat. The mat, dried as it comes from the machine, makes the low-density, insulating board type. Hardboard is made by drying sections cut from the mat on a gauze screen under pressure. The screen allows the steam generated to escape. Superhardboard is hardboard that has been treated with a drying oil (commonly tung oil) and matured.

57. Laminated fibreboard is built up by combining together several plies or laminations of paper-like material by means of a suitable adhesive.

58. Fibreboards are used in building for a variety of purposes, the low-density type principally as thermal insulation and for purposes of sound control, the hardboard type, as wall and ceiling linings, as floor coverings, and as linings for concrete shuttering.

59. COMPOSITE BOARDS. The plastics technique and the development of synthetic adhesives simplify the production of composite boards, formed from two or more different kinds of material, and make it possible to combine the individual advantages and eliminate individual disadvantages in the different materials. Insulation boards, for example, have excellent heat-insulating properties, but are soft and easily damaged, and their appearance is not always all that could be desired. Laminated plastics, on the other hand, have no special heat-insulating value, but have a good appearance, and are strong and not easily damaged. A combination of the two offers obvious advantages. Similarly, plywood veneered with a laminated plastics sheet provides a wear-resistant and hygienic surface for table-tops and counters.

60. Panels used as wall linings need to have a certain degree of stiffness and, in forms of stressed skin construction, must have the requisite resistance to buckling. Thermal resistance is an advantage. Composite boards can be made to meet these requirements. In the thicknesses required to give adequate stiffness and stability laminated plastics are relatively heavy and expensive. By using a facing on a light inexpensive core there is a saving in cost and weight and the thermal resistance is improved. Composite materials having a laminated plastics surface with a core of cellular material are being used in aircraft construction. The experience so gained will eventually be available for application to building.

61. There was, before the war, a limited production of composite boards made of hardboard faced with laminated sheet and of plywood veneered with plastics sheet or with metal. In the United States "fibre-tile boards" are made from hardboard coated on one side with a white or coloured plastic, which can be scored to resemble ceramic tiling, if need be, and are intended for use in circumstances where the cost of ceramic tiling would be prohibitive. Composite boards made of fibreboard faced with asbestos cement sheet have also been made in the United States and used for the rapid construction of houses for workers in the new armament factories.

62. Development of composite materials adapted to meet specific building requirements merits study with the object of making samples for experimental trial and developing the possible field of uses in the building industry.

TRANSPARENT OR TRANSLUCENT PLASTICS

63. The use of plastics in the form of transparent, glass-like sheets has become prominent by reason of their application to the construction of gun-turret enclosures and observation domes in aircraft. Transparent plastics are made from acrylic resins, vinyl resins, styrene resins, cellulose acetate and ethyl cellulose. Transparent cellulose acetate sheet reinforced with wire mesh has long been available for building use in place of glass.

64. Transparent plastics are made in sheet form by various methods according to the particular material used. Cellulose plastics, such as cellulose acetate, celluloid and ethyl cellulose, are processed and pressed into blocks and then sliced on special slicing machines to the thickness required. They are then polished in a polishing press with special plates to give them a mirror-like finish. Acrylic resins and styrene are manufactured by casting the material in moulds; vinyl chloride-acetate sheet by passing a dough-like mass through a calender mill and subsequently pressing the sheets between polished platens. Translucent or opaque sheets can be made from these various plastics by compounding with suitable ingredients.

65. Being thermoplastic the sheets can be readily shaped to any desired curvature. This is often done simply by warming the sheet and stretching it over a former.

66. The sheets are lighter and tougher than glass but are relatively easily scratched. A method of hardening the surface of polymethyl-methacrylate by depositing a film of silica has been applied to spectacle lenses. Transparent plastics have a high transmission factor for ultra-violet light.

67. Polymethyl-methacrylate and polystyrene have a high degree of transparency. A beam of light directed along the axis of a rod follows the curvature of the rod, and the material has been used to make light-directing fittings for instrument panels and medical appliances.

68. Transparent cellulose acetate and polymethyl-methacrylate have been used in buildings in place of glass in circumstances where their lightness, freedom from splintering, or ultra-violet light transmission have been desirable characteristics.

Polymethyl-methacrylate sheet has also been used for glazing pictures in public galleries. It tends to acquire an electrostatic charge which causes it to collect dust, but this defect can be overcome by suitable treatment.

69. The weathering properties of the synthetic glasses are not by any means as good as that of silica glass and it is unlikely that they would be readily acceptable for window glazing in domestic housing. But for sanatoria and for horticultural buildings their good ultra-violet light transmission may be sufficiently advantageous to warrant their use.

MATERIALS FOR THERMAL INSULATION

70. Sheets or slabs built up in a cellular form from thin films of cellulose acetate are in regular production as heat-insulating materials, and have been much used in transport vehicles. Polystyrene, phenolic, urea and vinyl resins and cellulose acetate have been produced as "expanded" plastics, having a foam-like structure. These, too, have good insulating qualities. They are exceedingly light in weight and are less susceptible to the effects of water, salt and fungi than are some of the materials normally used in cold-store insulation. They are easily fixed. They can be cut with a knife and the thinner sheets can be bent to any reasonable curvature.

PLASTICS PRODUCED IN CONTINUOUS LENGTHS

71. Plastics products in continuous lengths are manufactured by an extrusion method, the heat-softened plastic being forced through a heated steel die of appropriate shape. This method has long been applied to thermoplastics. Its application to thermosetting plastics is a much more difficult matter, because the temperature of the dies and the flow of the moulding powder have to be so adjusted that the product emerges in a properly-cured condition without risk of its setting prematurely in the die. Success was achieved some nine years ago. So far, only one or two firms in this country have the process in operation.

72. Extruded rods and tubes in any desired cross section and up to 4 in. in diameter, and products designed for use as beadings, cover strips, curtain rail, picture rail, wiring conduit, piping and so on, are in regular production in plastics.

73. The extrusion process is also used for making insulated wires and cables. Polyvinyl chloride and polyethylene are now being used extensively for cable sheathing and insulation in a range of grades of flexibility. The more rigid grades need only to be warmed in hot water to bend them to shape. Metal screening can be introduced in the manufacturing process. There is already in use a range of metal-screened cables embodying plastics dielectrics. Metal screens can be applied to plastics ducts by the methods now in use for applying screening to cables.

74. Laminated plastics have been made in continuous lengths in shapes that can be formed by using open-ended moulds and advancing the material step by step through the mould.

75. A similar step-by-step moulding process has also been used to make plank-like units reinforced with continuous cords of cotton or flax.

MISCELLANEOUS PRODUCTS

76. Besides those already dealt with, the plastics industry furnishes certain other products, which do not call for a description of the manufacturing methods, but which occupy more or less important spheres in building operations.

APPLIED FINISHES

77. The "applied finishes" referred to in this Report are paints, varnishes and lacquers incorporating synthetic resins in their composition.

78. A large proportion of the total production of synthetic resins is used in the manufacture of applied finishes. Of those that can be used for this purpose the most important for decorative finishes are modified phenolic and glycerol-phthalic anhydride resins. The former are cooked into drying oils to give varnishes and paint and enamel vehicles, and solutions of the latter serve the same purpose. The cost of these resins is greater than that of the natural resins they replace, but their use is justified by their greater uniformity as compared with the natural product and the improved properties imparted to the finish. By suitable formulation and combination of the two main classes mentioned it is possible to obtain most of the properties called for in finishes for buildings of all types, namely, durability, good colour retention, ease of application and hardness.

79. In addition, there are available 100 per cent. phenolic resins which give finishes of outstanding performance and these can be used to reinforce natural resins to give the same results as the modified phenolics. This method of improving the properties of natural resins has the advantage of giving flexibility in formulation.

80. There are, of course, many other materials such as nitrocellulose, urea resins, melamine resins, etc., which are used in applied finishes.

ADHESIVES

81. Synthetic resin glues have been referred to in the description of resin-bonded plywood. They are made in both hot- and cold-setting forms. They have been produced as "gap-filling" glues, which will function satisfactorily in a thick glue line. This property is of great importance because in assembly work it is often impossible to apply sufficient pressure to bring the wood surfaces into as close a contact as would normally be required. Gap-filling glues permit the construction of large structures such as roof trusses, laminated beams and arches without elaborate pressing equipment, and confer on such structures a high degree of moisture resistance. Glued construction is being used in aircraft and in certain types of hut now in use. From American sources comes information on the construction of built-up beams up to 110 ft. in length and arches for clear spans of 80 to 100 ft. Wood in sizes normally too small for structural work has been utilised in some of these designs.

82. The gluing of laminated plastics formerly presented great difficulty. Special glues to perform this function have now been evolved and are capable of making joints between laminated sheet which are stronger than the sheet itself. These joints require the application of heat and pressure.

PART II. APPLICATION OF PLASTICS TO BUILDING USES

83. In discussing the application of plastics to building uses it is convenient to consider:

1. Applications to the building structure:
   - Load-bearing members.
   - Linings or coverings for walls, ceilings and floors.
   - Structural components.
2. Fittings.
3. Tubes and pipes.
4. Applied finishes—paints, varnishes and lacquers.
5. Miscellaneous uses.
6. Manipulation and fixing.
7. Long-term uses.

84. The term "structural component" is adopted, for want of a better, to describe doors, windows, fireplaces, skirtings and so on which are installed by the builder in the normal course. It is not meant to include stanchions, rafters, purlins and joists, for which the term "load-bearing members" is used. "Fittings" are specific articles such as taps, switches, door furniture and the like used in the general equipment of the building or in the installation of electrical, plumbing, heating, lighting and other services commonly undertaken by specialist craftsmen after the shell is completed.

85. ALL-PLASTICS BUILDINGS. Complete structures for exhibition purposes have been built more or less exclusively of plastics. In an American example, walls and doors were made by moulding vinyl resin over fireproofed paper pulpboard, the walls being formed in 2-ft. panels held in position by steel rods. The floor tiles were moulded from a vinyl resin moulding powder and the skirting and ceiling mouldings were extruded sections. A "synthetic house" was exhibited at the Building Exhibition in Frankfurt in 1938. The walls were stated to be of light-weight blast-furnace slag concrete blocks jointed with an urea-formaldehyde resin, the flooring of another resin not specifically described; the tiles and timber were of laminated plastics and the plumbing of plastics. But there is a world of difference between an exhibition model, designed to attract attention regardless of cost or practicability, and a house intended for permanent use. While many of the features described as having been exhibited were doubtless of practical interest, the designers would probably be the last to wish to convey the impression that all were suitable for immediate application to building practice.

86. But what is impracticable today may become practicable in the future, though there must always be a lag in the general adoption of new developments consequent on the need for assurance that the material or article in question will adequately fulfil the purpose for which it is intended. Knowledge of the properties of the materials and of the conditions to which they are to be exposed in the particular form of use can guide judgment as to whether a proposal is promising or otherwise, and can show the directions in which improvement can be sought. The ultimate test of a promising development is practical trial.

87. Some applications of plastics to buildings are already well established; some are being tried tentatively; others have yet to be examined by trial and experiment. Attention will for the moment be directed to a consideration of present practice and new proposals in so far as they can be regarded as practicable or impracticable now or in the immediate future.

1. APPLICATION TO THE BUILDING STRUCTURE

LOAD-BEARING MEMBERS

88. There was, before the war, some discussion in the technical press on the possibility of making building blocks and roofing tiles in plastics. Much more has since been said on the utilisation of plastics as building materials. At first the leading motive was to find alternative structural materials, though in the outcome the plastics industry has found itself so fully occupied that there has been little material or plant capacity to spare to make much increased quantities of building products. In consequence, attention in some quarters has now turned to the prospect of using plastics as structural materials in post-war building.

89. Since thermoplastics soften at comparatively low temperatures, the risk of collapse in case of fire makes it quite impossible to contemplate their use as load-bearing members. This leaves only the thermosetting plastics for consideration.

90. The materials used to carry structural loads are of two kinds: those like brick, stone and concrete, which are used in compression and never by design in tension, and those that can be used either in compression or in tension. Wood and steel are the materials normally used in tension. If plastics are to be used as tensile materials in building they must bear comparison with wood and steel.

91. PLASTICS "BRICKS" VERSUS CLAY BRICKS. Building blocks could be made with a synthetic resin binder, and might conceivably be made at a competitive price, though this is doubtful at present. Such blocks might be lighter, but would not compare in durability with clay bricks or concrete building blocks. Clay and Portland cement, though not included within the range of plastics, are in effect inorganic plastics—clay, a thermosetting plastic maturing at a high temperature, Portland cement a cold-setting plastic. To use synthetic plastics in place of clay and Portland cement, of which there are abundant supplies, would need to be justified by their having overwhelming advantages. Of this, there is no immediate prospect. Manufacture of building blocks would, therefore, seem to involve a wasteful diversion of valuable materials so long as plastics are in short supply.

92. PLASTICS VERSUS STEEL AND WOOD. Turning now to tensile members, floor joists, rafters and purlins must be strong enough to carry the imposed load with an adequate margin of safety and be stiff enough to carry the load without excessive deflection. The requirements for steel are set out in *British Standard* 449–1937. The use of wood and steel in building is governed by building by-laws. There are at present no statutory requirements governing the structural use of plastics. Such requirements would obviously need to be formulated before their use were permitted. But the properties of most plastics are not very suitable for the purpose. The difficulty is that the modulus of elasticity is disproportionately low when compared with the tensile strength. In consequence, a beam of any normal section made to be just strong enough to carry the load with safety, deflects excessively, and if made large enough to keep the deflection within an acceptable limit, the strength is such that the factor of safety is five or six times larger than it would normally need to be. Such increase in dimensions is accompanied by a corresponding increase in cost.

93. The difficulty might be overcome by adopting a specially designed section having a high ratio between the depth and width, taking due precautions to prevent buckling. But development on these lines would not be warranted at present, because thermosetting plastics are defective in another respect, namely, that they are lacking in ductility. Apart from this the effects of fatigue and creep under load also need careful study.

94. Ductility is an important requirement in a structural member, since it provides the mechanism for distributing the stresses and for avoiding their concentration in one member or at particular points. Without some degree of ductility the strength of the material is not fully utilised. Furthermore, the structure may be dangerous, because the formation of cracks and other signs that accompany stress distribution and give warning in the event of overloading do not show themselves. For the same reasons, plastics are unsatisfactory when used in place of steel as reinforcement for concrete.

95. It is considered, therefore, that the moulded and laminated plastics at present available are unsuitable for use as tensile structural materials, thermoplastics by reason of their low softening temperatures, and thermosetting plastics by reason of their behaviour under load and the consequent risk that an overloaded member might collapse without warning.

96. With resin-bonded plywood and laminated wood, however, the circumstances are different. These retain the characteristics of wood, one of which is its pseudo-

ductility, resulting from its tough, fibrous structure, which prevents undue concentration of stress and causes an over-loaded wooden beam to give due warning before collapse occurs. Manufacture of plywood and laminated wood is an economical method of using timber. The products can be shaped in the course of manufacture into units designed for structural use, and can be glued together *in situ* with synthetic glues that are unaffected by moisture and fungi. There have been tremendous advances in the use of plywood and laminated wood and of glued construction in aircraft, and there is already some experience in their application to buildings, particularly in the United States.

97. For much the same reasons as those described, plastics other than resin-bonded plywood have not yet been used in aircraft construction for any but unstressed or lightly-stressed parts, and certainly not yet for the structural framework. The advent of new materials or processes may in time change the outlook for plastics as structural materials. Meanwhile, the building industry might well be guided by past experience and such future developments as may take place in the use of plastics for aircraft, where their lightness offers greater inducement and where cost is a less onerous restriction than it is in building.

98. STRENGTH-WEIGHT RATIO. Before leaving this aspect of the subject, reference should be made to the density and strength-weight ratio of plastics. The comparatively low density of plastics is sometimes spoken of as if a very considerable saving in weight would result from using plastics in place of steel. But it is not the density alone, but the strength-weight ratio that determines the saving in weight, and this ratio is not very different for steel and plastics. In other words, the dimensions of a structural member have to be increased so much to compensate for the lower strength of plastics that much of the advantage accruing from their lower density is lost. But where flexural rigidity is the more important consideration, a material of low density has an advantage, because sections can be made thicker for the same weight, and the flexural rigidity increases in greater proportion. As flexural rigidity is the factor that determines the resistance to buckling of struts, compression flanges of beams and shear members, the material having the highest value of $\frac{E}{\rho^2}$ or $\frac{E}{\rho^3}$, depending on the precise conditions (E being the modulus of Elasticity and ρ the density), will be the best in this respect. In such applications reinforced plastics offer considerable promise.

LININGS OR COVERINGS FOR WALLS, CEILINGS AND FLOORS

99. The laminated and other sheet materials described in Part I have been used extensively as linings for walls and ceilings. Their manipulation and fixing are dealt with in a later paragraph. It will be sufficient here to review such points as call for special comment.

COST

100. A table of comparative costs of sheet materials is given in Appendix II. Laminated plastics have hitherto been used mainly in public and commercial buildings and in shipbuilding. Their hygienic qualities, water resistance, good appearance, ease of cleaning and wearing qualities fit them for domestic use, particularly in bathrooms and kitchens, though it cannot be denied that their higher cost as compared with fibreboard, plasterboard or asbestos cement sheet tends to limit their use. It is unlikely that manufacturing costs can be reduced to any considerable extent, but it may be hoped that it will be possible to manufacture composite boards at no greater cost and possibly at a less cost than for solid laminated plastics, which, besides retaining the desirable surface characteristics,

will offer additional advantages and a more useful combination of properties, and serve to extend the utility not only of the plastics products themselves, but also of the materials with which they can be associated. Thus, facing with laminated sheet can be expected to diminish or eliminate the fire risk associated with insulating board, without detriment to its insulating qualities. Similarly, such facing would compensate to some extent for the brittleness of asbestos cement and would remove difficulties experienced in its decoration. No more than the fringe of these possibilities has been explored.

COLOUR

101. That plastics can be made in a wide range of colours and do not need decoration is an advantage in the first instance and a more or less permanent advantage in public and commercial buildings, where, so long as the effect is generally pleasing, personal idiosyncrasy need not be catered for. But domestic interior decoration is very much a matter of personal taste, and a permanent colour scheme in a living room or bedroom may not be altogether acceptable, especially to an owner occupier. Such objection, if objection it be, would not apply with the same force to the use of self-decorative plastics in bathrooms and kitchens. Used in rented flat property, laminated plastics have been the subject of favourable comment in the technical press on the ground that their resistance to wear and tear saves expenditure on redecoration at each change of tenancy. Even so, laminated plastics, despite their hard-wearing qualities, cannot be expected to retain their pristine appearance indefinitely. Some tints fade in strong light, whether used in plastics or otherwise. For these reasons, suitable paints will need to be available to decorators and the general public.

COVER STRIPS

102. Insulating board and plywood can be supplied in sizes large enough to cover the walls of rooms of moderate size without breaking the surface with vertical joints. The other materials dealt with are not normally made in such large sizes. It is possible that laminated plastics can be produced with the edges shaped in the course of manufacture in such a way as to eliminate the need for cover strips to conceal the joints. This point is being investigated.

103. Where cover strips are needed the customary materials can be used, or strips can be cut from sheets of the lining material itself. Cover strips can also be supplied in extruded plastics in any length required and in any desired cross section. Extruded plastics can also be made in the form of fixing strips designed to hold the edges of the boards.

WEATHERING QUALITIES

104. Laminated plastics have been used to a limited extent out of doors as external wall coverings, principally in commercial buildings. These and resin-bonded sheets made by the pre-mixing process tend to lose their gloss comparatively quickly out of doors and to become shabby. Some are affected more quickly than others. They are not at present eminently suitable for outdoor use in domestic buildings where cost of maintenance is of major importance. Developments aiming to improve their durability are to be expected. Production of suitable paints, accompanied by education of the public in their use, would permit restoration of the weathered surfaces, but there is at present little information available on the use of paint on plastics.

105. Unpainted resin-bonded plywood is known to have weathered for periods up to five years without showing the least sign of deterioration. It is unlikely that older examples will be found for examination. Satisfactory behaviour over longer periods is to be expected but, for permanent buildings, painting, varnishing, oiling or periodical treatment with a wood preservative is desirable.

106. Hardboard and superhardboard, with a suitable paint treatment, have been used quite extensively out of doors for building and for caravan and van bodies and advertisement signs.

107. Some resin-bonded wood-waste boards are known to have weathered satisfactorily over short periods of 12 to 18 months. Longer experience is lacking, but the boards so far produced have for the most part been made with a comparatively low resin content, and are unlikely to be suitable for prolonged use out of doors. Higher resin content, which would improve durability, tends to make the boards difficult to nail. Boards made with asbestos waste promise to be more weather-resistant than those made with wood waste.

DIMENSIONAL STABILITY

108. In contact with air maintained at constant temperature and humidity, non-metallic materials absorb or lose water until there exists a state of equilibrium between the moisture content and the water vapour in the surrounding air. Change in the relative humidity of the environment is accompanied by a corresponding change in moisture content in a direction tending to re-establish equilibrium under the new conditions. Hence under normal conditions of use the moisture content tends to vary with changes in the temperature and humidity, fluctuating between two extreme conditions corresponding approximately to the upper and lower limits of the range of air conditions. Absorption of moisture is accompanied by expansion, loss of moisture by contraction and the dimensions fluctuate accordingly. Some materials, fibreboards particularly, respond very quickly to change in the conditions of the environment; others, such as laminated plastics, respond slowly.

109. Some apprehension has been expressed that the moisture expansion of plastics may be such as to hamper their use in building. The question of dimensional stability is particularly relevant to the use of sheet materials as linings, and it can conveniently be considered here.

110. The building industry is accustomed to handling materials that expand and contract with changes in the moisture content, and all due precautions are taken to minimise the ill-effects that would otherwise occur. Wood, for instance, is normally seasoned before use, and should be brought to a moisture condition appropriate to the particular purpose for which it is to be used. Wood panelling is not restrained, but is set in slots to accommodate the small changes in dimensions that accompany the normal variations in humidity.

111. In the form of plywood the dimensional movements of wood are subject to restraint in the length- and width-wise directions of the sheet. This restriction in movement implies the imposition of stresses, and care is always taken in the manufacture of plywood to ensure a balanced construction to avoid warping. There is, of course, no restraint in the direction of the thickness of the sheet.

112. Impregnation of timber with synthetic resins reduces its moisture expansion considerably.

113. Fibreboards undergo dimensional changes of the same kind. Here again the builder is accustomed to making allowance for expansion and contraction. The boards which, as has been said, respond very quickly to the condition of the environment, are removed from their packages and are allowed to stand for 24 to 48 hours in the room in which they are to be used. They are fixed with a small gap between adjacent boards, and some makers recommend that only one edge and the intermediate studs or battens should be nailed, the unnailed edges being left free to move behind the cover strips. The latter precaution cannot, of course, be adopted when other methods of joint treatment, such as bevelling the edges of the boards or covering with strips of paper or skrim, are adopted. However,

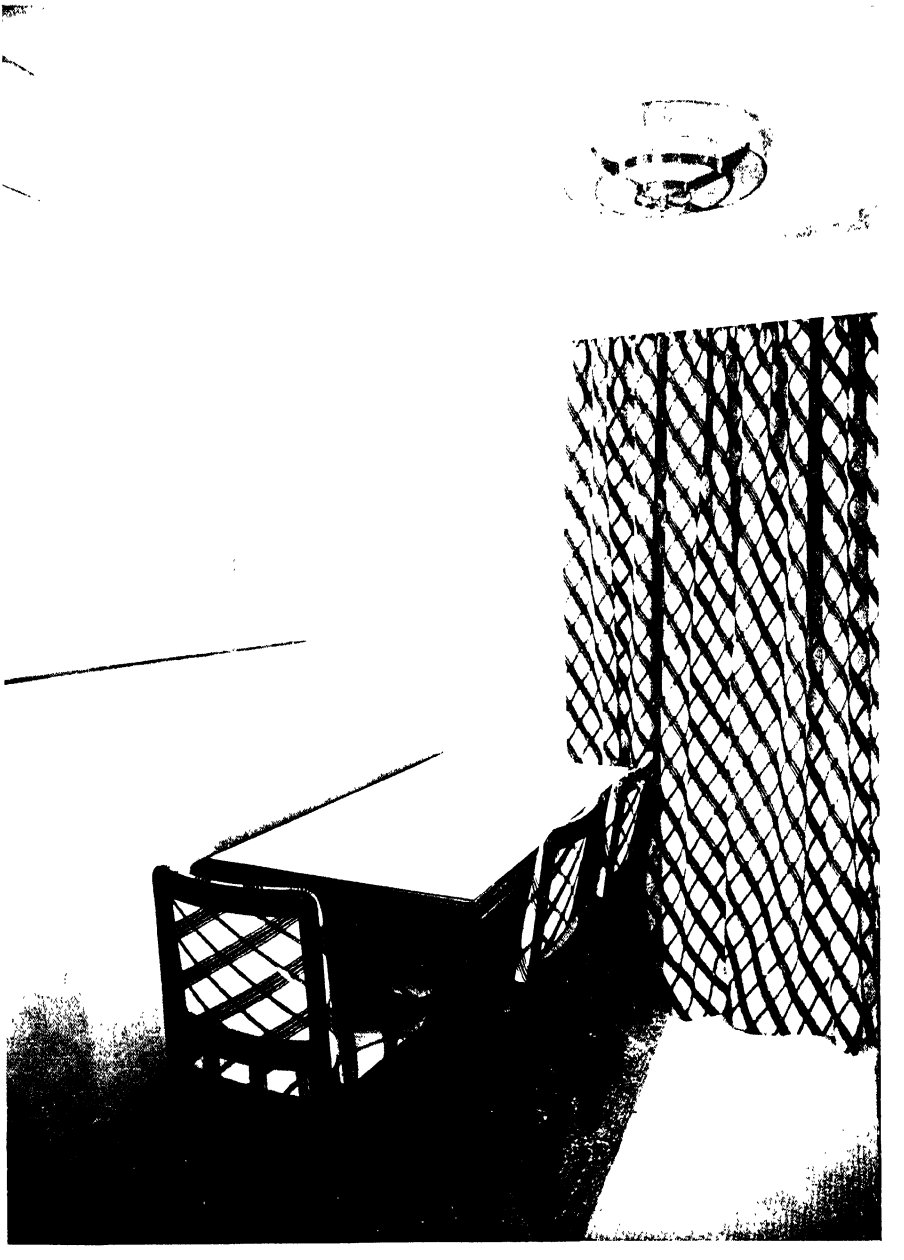


FIG. 1. DECORATIVE TREATMENT IN SHEET PLASTICS—WALL PANELS AND TABLE TOP



FIG. 2. STRESSED SKIN CONSTRUCTION IN RESIN-BONDED PLYWOOD

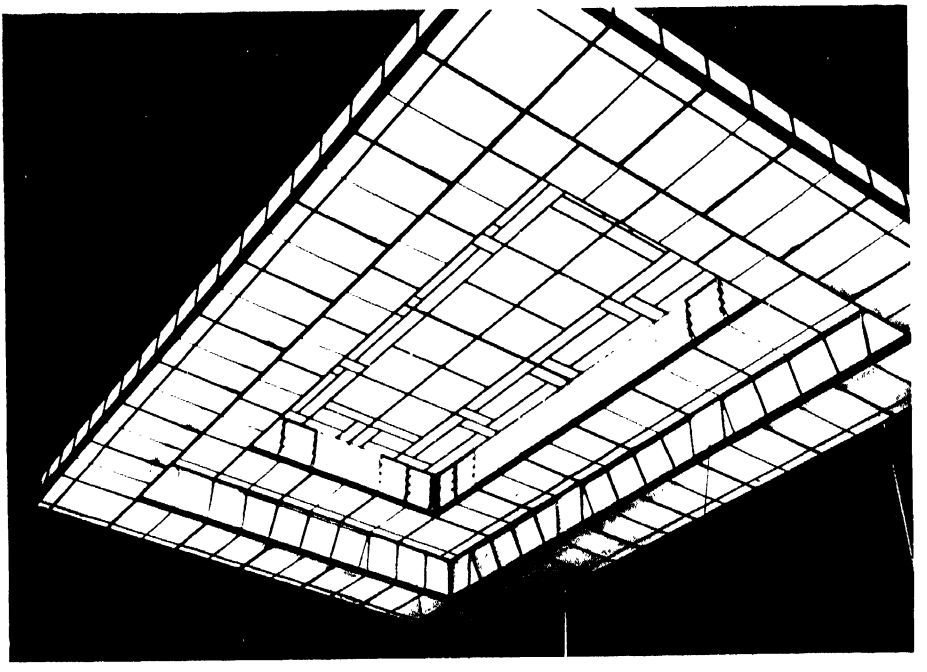


FIG. 3. PLASTICS LAYLIGHT GLAZING

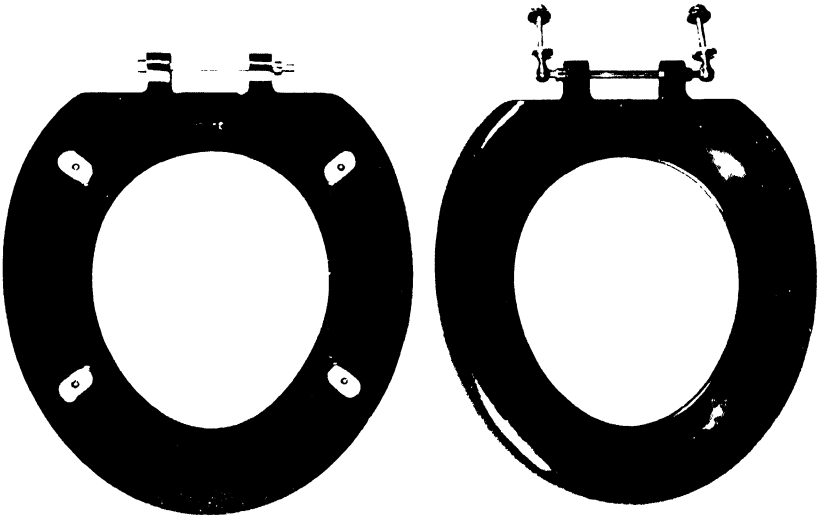


FIG. 4. TOILET SEAT (UPPER AND UNDER SIDES)

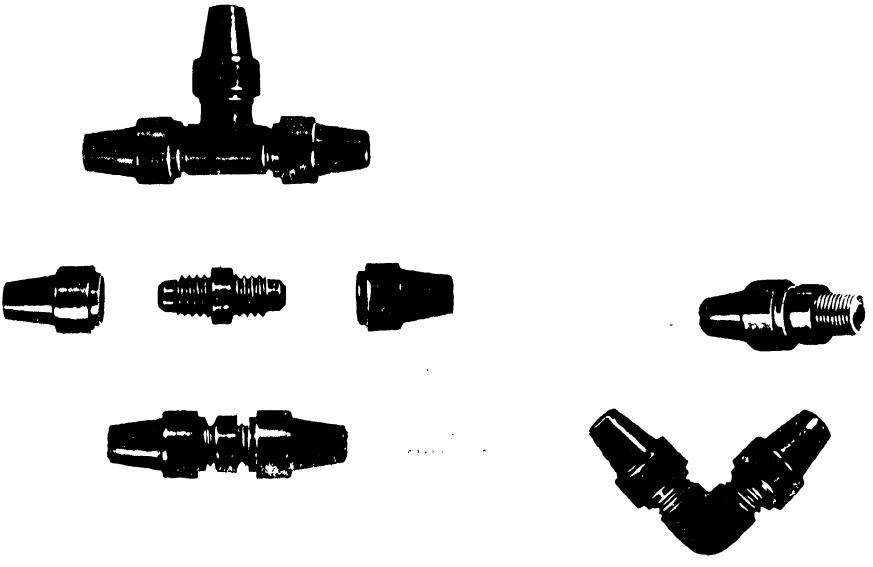


FIG. 5. EXTRUDED TUBING AND MOULDED FITTINGS

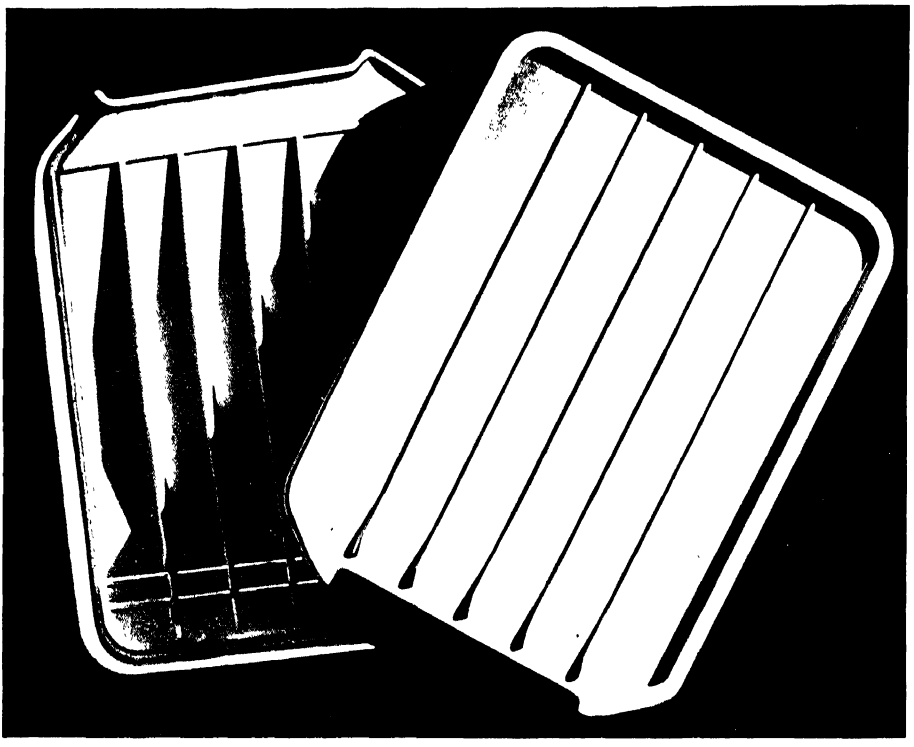


FIG. 6. DRAINING BOARD (UPPER AND UNDER SIDES)

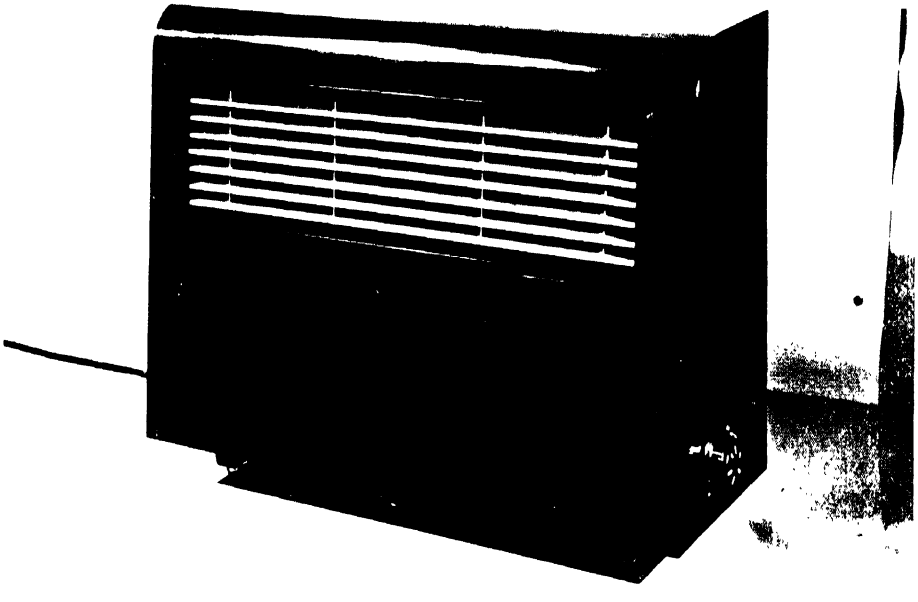


FIG. 7. MOULDED CONVECTION HEATER

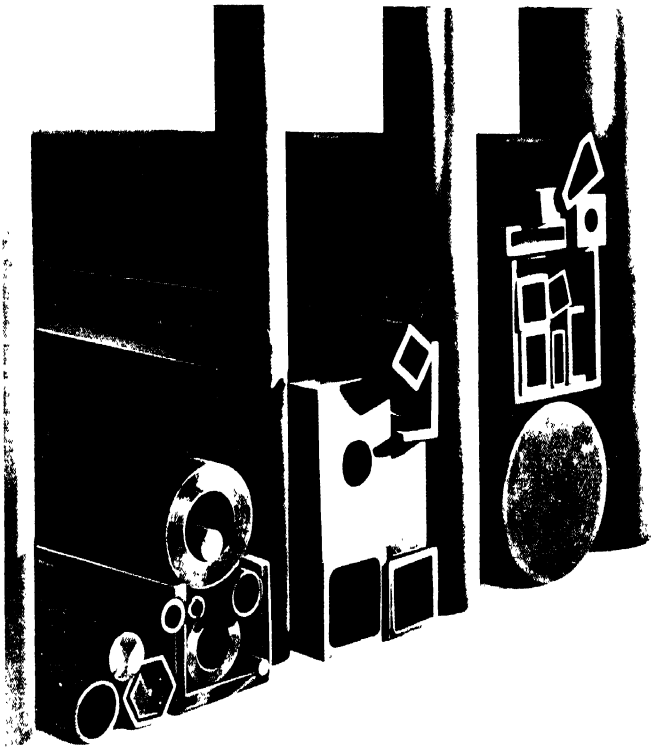
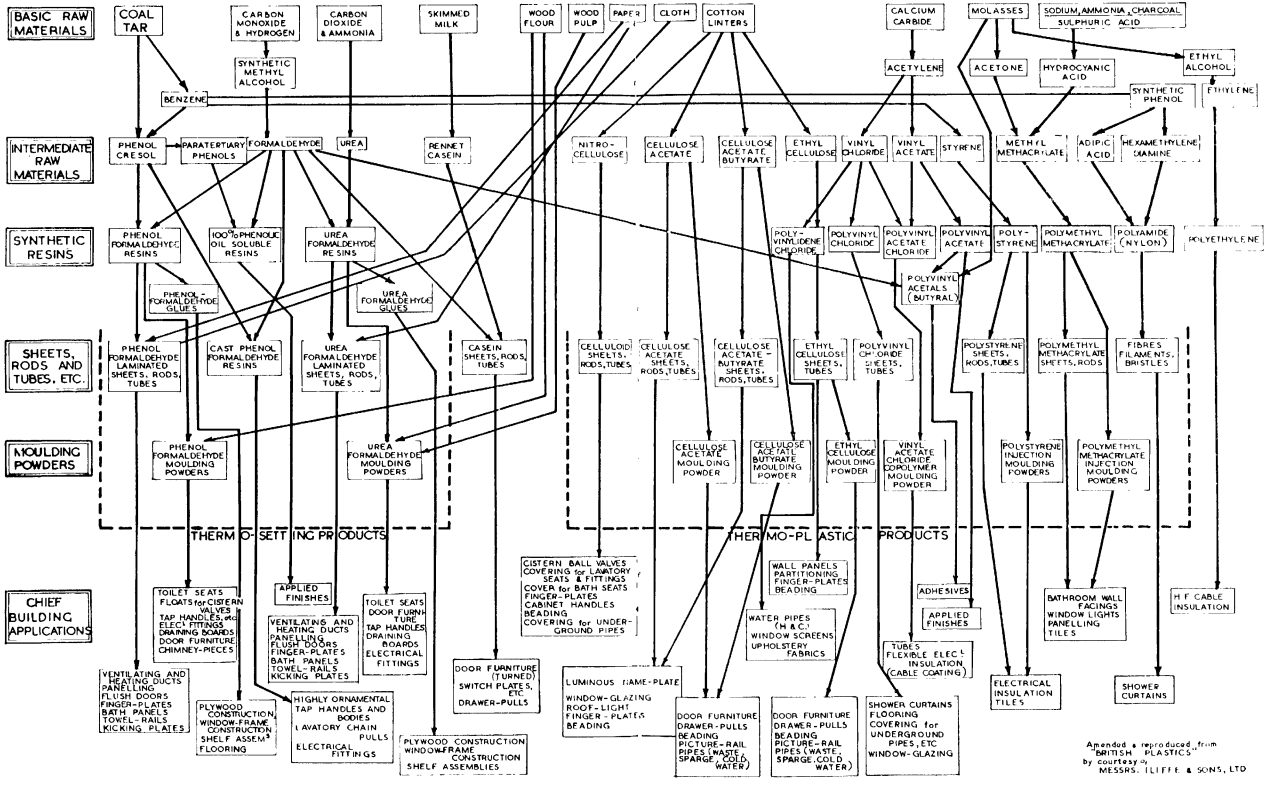


FIG. 8. MOULDED LAMINATED PLASTICS



FIG. 9. MOULDED LAMINATED PLASTICS

CHART OF CHIEF PLASTICS MATERIALS



Amended & reproduced from "BRITISH PLASTICS" by courtesy of MESSRS. ILIFFE & SONS, LTD

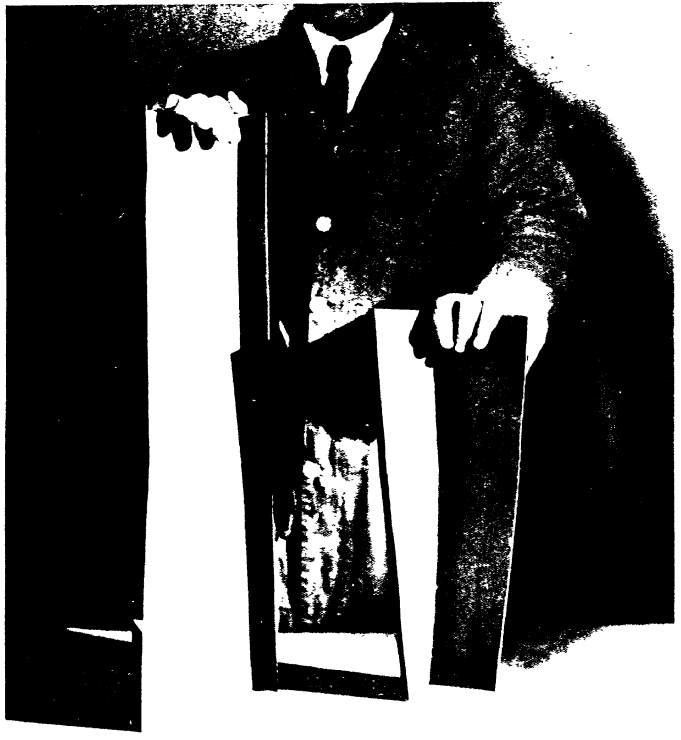


FIG. 10. MOULDED LAMINATED PLASTICS

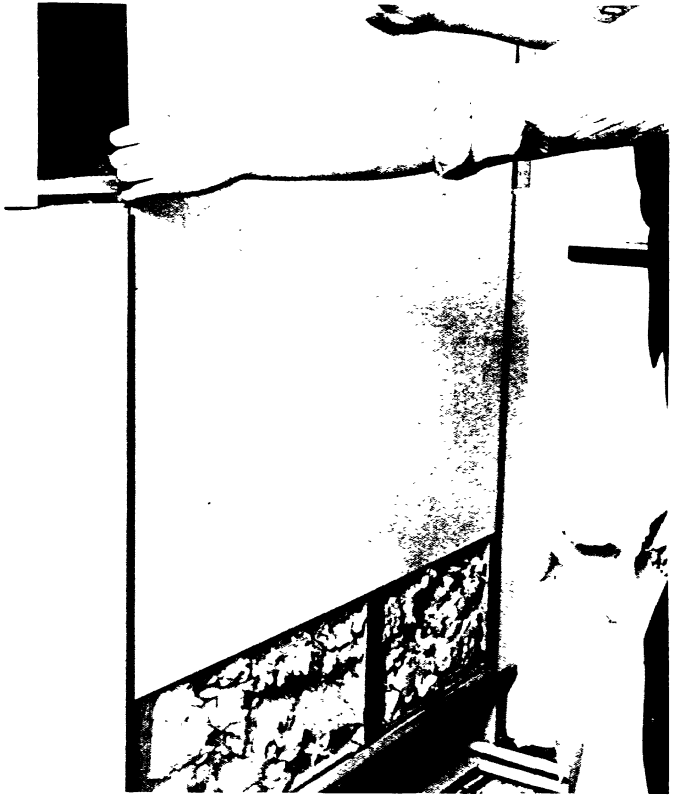


FIG. 11. FIXING LAMINATED SHEET PANEL



FIG. 12. MOULDED AIR EXTRACTOR

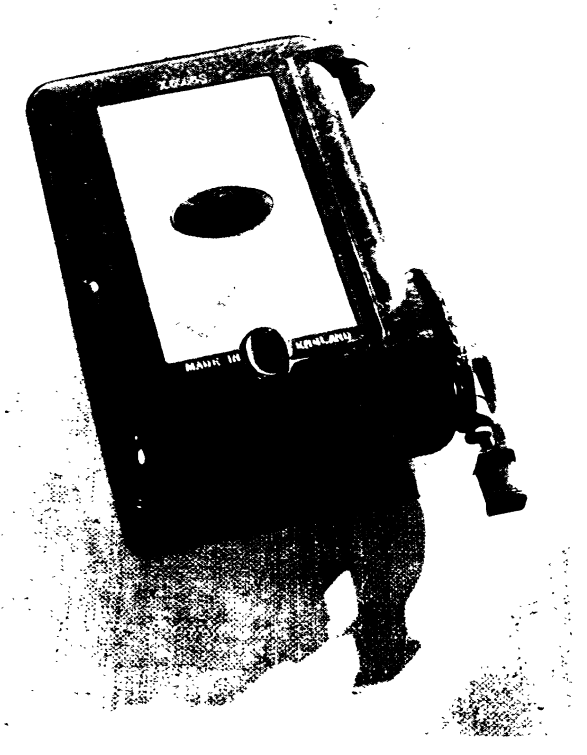


FIG. 13. MAINS SWITCH AND FUSE BOX

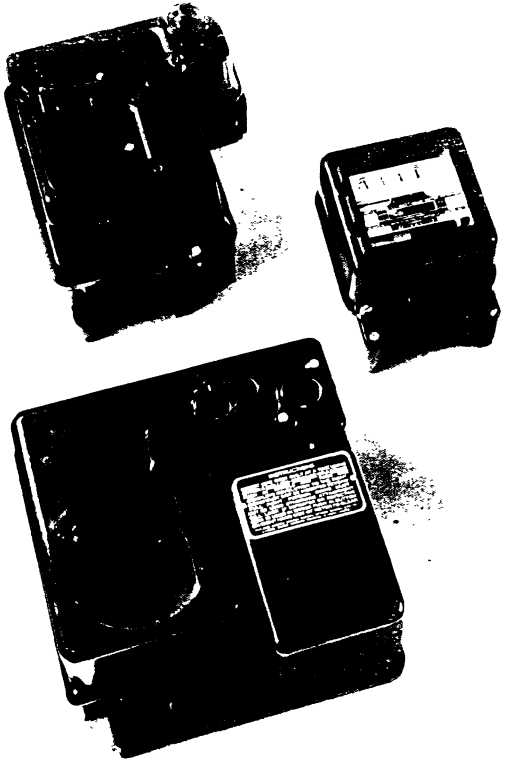


FIG. 14. ELECTRICITY METER CASES

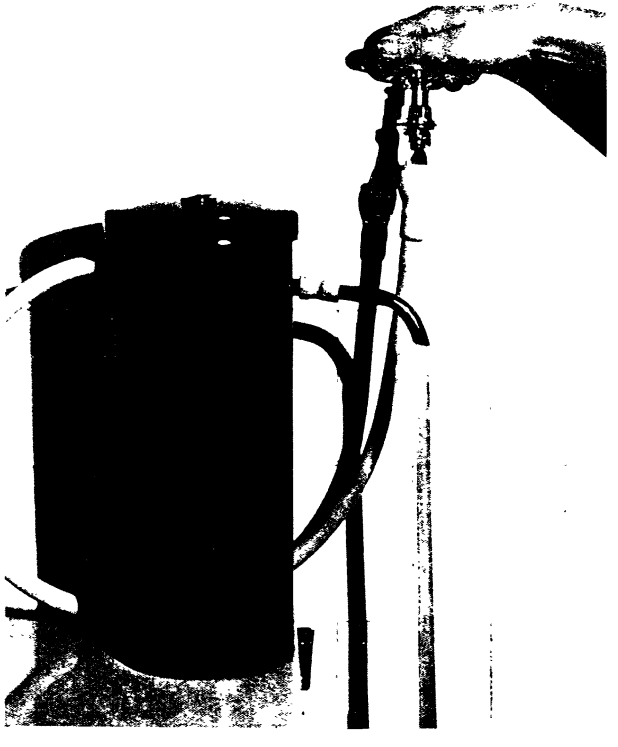


FIG. 15. MOULDED WATER-SOFTENER CASE

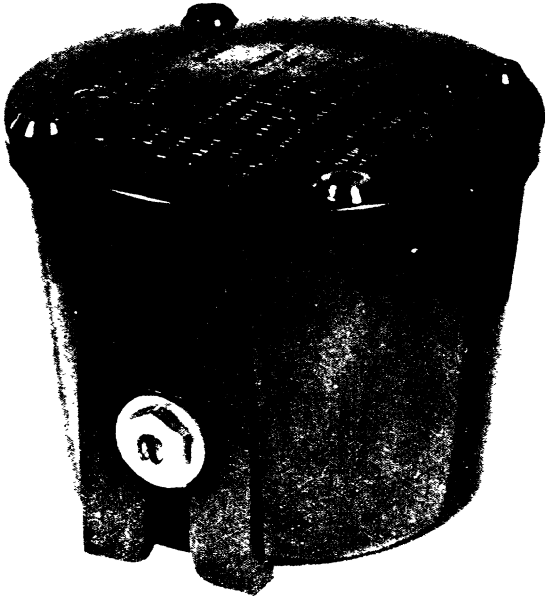


FIG. 16. MOULDED CISTERN BALL FLOAT

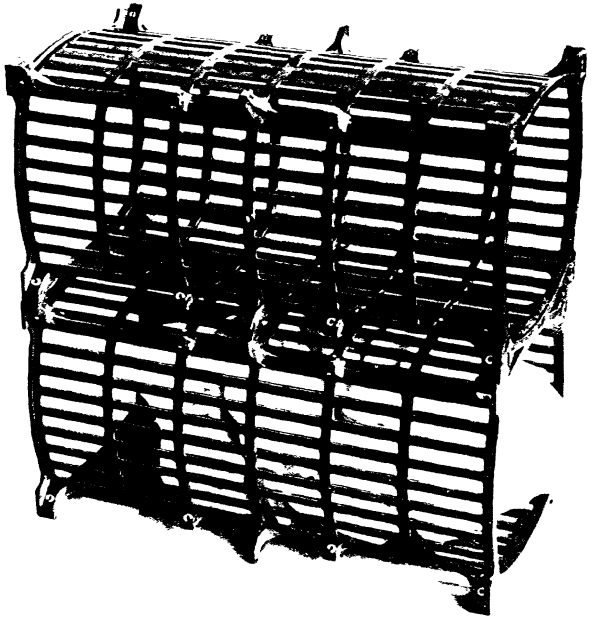


FIG. 17. MOULDED CLOTHES CONTAINER FOR GYMNASIUMS



FIG. 18. HEAT-INSULATING MATERIAL

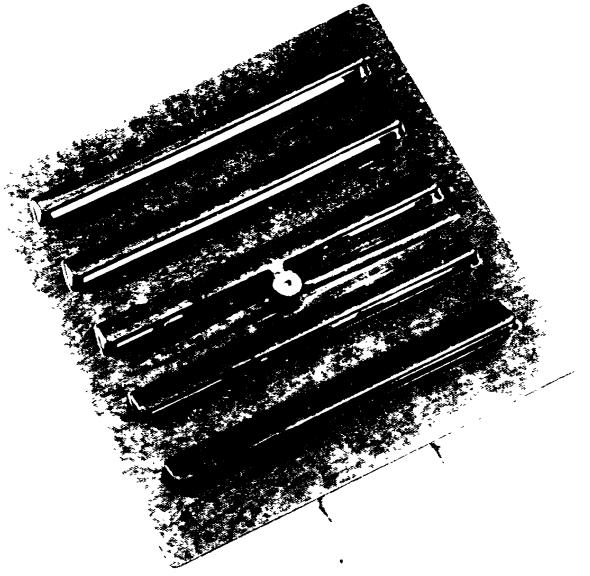


FIG. 19. MOULDED VENTILATOR

provided the boards are brought to a normal moisture condition before they are fixed and are not tightly butted, no practical difficulty is experienced.

114. Laminated and other plastic sheets are subject to similar dimensional movements. Their dimensional stability has not yet been investigated as thoroughly as that of wood, or with the same specific attention to the conditions met with in building use. Such published data as there are have related to tests involving prolonged exposure to dry heat or to conditions of high humidity or continuous immersion in water, which may possibly provide some guidance on the behaviour to be expected under tropical conditions, but which are not closely related to conditions experienced in this country. Even so, the resulting dimensional changes reported, though large for some types of plastics, are comparatively small for others. It is believed that measurements of the dimensional changes that occur when specimens conditioned at a normal temperature to an atmosphere of 30 to 40 per cent. relative humidity are subsequently stored in an atmosphere of about 90 per cent. relative humidity or vice versa (conditions that are commonly adopted for measurements on wood and fibreboard), are a more suitable comparative measure of the moisture movements likely to be experienced in building use in this country. Measurements made under these conditions indicate that the dimensional changes in most types of plastics sheets are not materially different from those for other materials which the builder in the normal course handles without difficulty.

115. Cellulose acetate and casein products require separate consideration because it is known that the dimensional movements are greater than those experienced with most other plastics. Manufacturers are aware of this and have been at pains to direct attention to it. Thus, cellulose acetate sheet is not recommended for use as wall linings; transparent or translucent cellulose acetate supplied for glazing is recommended to be fixed in such a way as to allow freedom for expansion and contraction; casein is not regarded as being a very suitable moulding material for building fittings.

116. Prolonged exposure to dry heat causes progressive shrinkage of cellulose acetate sheet accompanied by embrittlement. This is attributable to gradual loss of the plasticiser. Phenolic and urea plastics have also been observed to shrink under such conditions, though to a less degree. This shrinkage may be caused to some extent by "after-curing" of the resin, and be more pronounced with undercured than with fully cured material. But this aspect has not yet been fully investigated. As far as building practice is concerned in this country, exposure to dry heat is not a condition normally experienced except in close proximity to heating apparatus.

117. One other point needs to be mentioned. It might be thought that exposure to rain or condensation of moisture on the surface might in practice cause much greater dimensional changes than those brought about by exposure to an atmosphere of high relative humidity. But this is not generally so. Periods when absorption of water from these causes can occur are transient, and, in any event, it is in the early stages of wetting or the later stages of drying that the most pronounced dimensional changes occur. Green timber, for example, does not begin to shrink until its moisture content has been reduced to about 25 per cent., whereas the initial value may be 100 per cent., or more.

118. The slow response of laminated plastics to changes in the external conditions has the effect that a dry sheet exposed out of doors may slowly increase in weight and dimensions, and thereafter continue in a more or less steady condition. The slow response will also have a steadying effect on the changes experienced under indoor conditions.

119. Admittedly, the data available on the dimensional stability of plastics and their bearing on building practice are incomplete, and the subject will merit further study. Nevertheless, there has been enough practical experience to demonstrate that, provided the usual precautions are taken, sheet plastics supplied for use as wall linings can be used without their moisture expansion giving cause for dissatisfaction.

FLOOR COVERINGS

120. There has been relatively little experience of the use of plastics as floor coverings, and there is a lack of information on their wear resistance and general suitability. Plywood makes a satisfactory floor covering, provided the top ply is of adequate thickness. The water resistance of resin-bonded plywood is particularly advantageous in bathrooms and kitchens. Hardboard is supplied for use as a floor covering. The oil-treated "superhardboard" type has been used out of doors for dance floors, though only, as far as is known, in temporary exhibition buildings.

121. Wood-waste boards have been seen in use as floor coverings in a factory where they are made. They appeared to be satisfactory, but had not been in use for more than a short time.

122. Laminated plastics sheet might be used for flooring, but unlike plywood, which can be secret-nailed to a timber subfloor with panel pins, some difficulty might be experienced in fixing it. There is no information available on its wearing qualities.

123. Vinyl polymers in sheets of various grades of hardness have been used as floor coverings in Germany and the United States. There is at present little experience of their use in this country.

STRUCTURAL COMPONENTS

124. The use of plastics for making window frames, doors and door frames, skirtings and staircases, can only be discussed tentatively, because, apart from facings for flush doors and a very limited range of experimental trials in other directions, their adoption has not progressed beyond the preliminary stages. Some proposals are no more than rather nebulous suggestions. Experiments will need to be arranged to judge of their practicability. As the initial cost for moulds, where moulds are needed, will usually be high, such experiments cannot be undertaken until each proposal has been very carefully studied and decisions taken as to whether the expenditure will be justified by the expected need for, and utility of, the particular component in question.

WINDOW FRAMES

125. Moulded window frames have been made and used successfully in cars and in refrigerator display cabinets, and there has been enough experience in their production to indicate that there would be no difficulty in making fixed frames for borrowed lights in internal partitions. Frames for service hatches, with doors sliding in moulded or extruded channels, could be made in the same way.

126. Frames with opening lights, designed to suit the method of manufacture, could be moulded in complete units in shock-resistant moulding materials, or could be fabricated from laminated, moulded or extruded sections. Attention is being given in more than one quarter to projects of this kind. The fabrication method involves difficulty in fixing together the separate parts. The recent advent of synthetic glues, capable of making a sound joint between thermosetting plastics, may be helpful in this respect. Whether window frames in plastics can be made in attractive designs, strong enough to withstand hard use, and adequately resistant to the weather, remains to be seen. Weather resistance over indefinitely long

periods can hardly be expected; sooner or later the outer surfaces will need to be painted.

127. An immediate and effective application of plastics can be found in glazing strips, either moulded to length, complete with perforations for the fixing screws, or extruded in continuous lengths to be cut and fitted as required.

128. The use of transparent or translucent plastics as glazing materials has been dealt with elsewhere in this Report.

WINDOW BOARDS

129. Window boards could be fabricated in laminated sheet or in plywood with or without a facing of laminated veneer. They could be moulded in suitable lengths to any required pattern, or could be supplied in continuous lengths to be fitted as required. The method to be adopted depends on the design. Boards required with coved ends would need to be moulded in standard sizes.

DOORS

130. Flush doors have been made with facings of plywood or laminated plastics. The latter may be too expensive for general purposes, but there is much to be said in their favour where a door is subjected to hard usage. Laminated plastics have commonly been used for kicking-plates.

131. To make complete doors as mouldings would probably be too expensive, but mouldings on a light, inexpensive core may be worthy of further consideration.

132. There are reports from the United States of the manufacture of doors from plastics sheets set in a framework fabricated from extruded plastics.

133. Door frames could be made as mouldings. Trials would be needed to establish their suitability for the purpose.

STAIRCASES

134. With the invention and development of the rubber-bag process and the rapid progress that has been made in the production of large units used in the construction of aircraft, there is nothing unreasonable in the idea that complete staircases might be produced by a moulding process. For this purpose, wood veneers or a combination of wood veneers and resin-impregnated paper would seem desirable to provide the required strength and resistance to impact.

135. An allocation of equipment, materials and personnel would be required to explore the possibilities of a project of this kind. Prior consideration would have to be given to the question of design and dimensions, with close collaboration between the architectural designer and the plastics technician. Assuming that such a project can be pursued to a successful conclusion, there would be advantage in choosing a design to suit a particular design of house likely to be used in numbers for post-war housing. However, the moulds used in this process are comparatively cheap and can be altered without great difficulty. It would be less essential to settle the design in advance than with a moulded window frame, the mould for which would be expensive and could not easily be altered.

CHIMNEY-PIECES AND FIREPLACE SURROUNDS

136. Moulded chimney-pieces would be a practical application where large numbers of the same size and design are required. These could also be made in laminated plastics or in plywood faced with decorative wood veneer or laminated sheet.

137. Moulded fireplace surrounds in replacement of, or in conjunction with, porcelain tiling might be considered if they were suitably designed so as to insulate the plastic material from direct heat.

SKIRTING BOARDS

138. Skirting boards could be made from laminated sheet in lengths (at present) up to 8 ft., or could be extrusion moulded to any desired length. Extrusion mouldings could be designed with channels to accommodate electrical wiring or gas and water pipes.

139. Moulded units designed to be used as skirting boards have been produced experimentally with electrical heating elements embedded in the material. This method also lends itself to the manufacture of panel heating units.

2. FITTINGS

140. Plastics offer wide scope for the manufacture of fittings of all kinds. Such fittings include those needed in the equipment of electrical, plumbing, heating and lighting services, and such articles as door and window furniture, floor clips, draining boards and so on.

141. Some fittings have long been made in plastics and are familiar articles in daily use. The majority have performed their functions efficiently and so unobtrusively as to pass almost unnoticed. A few, by reason of poor design or irresponsible stinting of material, have failed to give the service demanded of them and have attracted a disproportionate amount of attention and adverse comment. Some, on the other hand, have attracted attention by their novelty and utility. Some fittings that might be made in plastics have yet to be tried. It can be taken as a guiding principle that plastics should not be used for any purpose unless there is a reasonable prospect that the article will be satisfactory. But it is not always possible to ensure complete satisfaction in advance. The merits or demerits of some applications must necessarily be assessed by trial.

142. It is not proposed to enumerate and discuss the individual fittings that have been or might be made wholly or in part in plastics. Some indication of their scope appears in Appendix I. But the application to plumbing calls for special comment.

143. Many sanitary fittings have been made in plastics, including plugs for baths and basins, tap capstans, the upper parts of tap bodies, handles for mixing valves, waste pulls, toilet seats and ball floats for cistern valves. A recent development in the manufacture of flushing cisterns has been the casting of two-gallon tanks in a bituminous compound. There has been, besides, an increasing use of plastics for water supply and waste pipes, more so abroad than in this country. In Germany and Japan such uses were dictated to some extent by the adoption of a policy of economic self-sufficiency.

3. TUBES AND PIPES

144. While the chemical resistance and hygienic qualities of plastics commend their use for piping in chemical works and breweries when other conditions permit, the cold-flow characteristics and the low softening temperatures of many thermoplastics, and also the lack of operatives experienced in installing them, tend at present to limit their domestic application. But experience is accumulating, and use for domestic water-supply piping is by no means beyond the bounds of possibility. Plastics possess an advantage in that their relatively low thermal conductivity reduces the risk of freezing. Further, they are not subject to electrolytic corrosion.

145. Extruded polyvinyl chloride tubes, shaped, welded and cemented together, were used for plumbing in the "synthetic house" shown at the Frankfurt Exhibition in 1938, and technical reports have since been published dealing with their properties and manipulation. Polyvinyl chloride tubes, it is said, cannot be used for hot water and must not be laid near hot-water pipes, since the material softens and creeps at temperatures above 50° C. On account of their creep characteristics they need more or less continuous support.

146. More recently it has been proposed in the United States to use a vinylidene copolymer for domestic piping and water-supply fittings, to ease the demand for metals. Investigations have been made to study the effects of temperature and the resistance to shock caused by water hammer, and to determine the best methods of installation. These led to the redesign of certain of the fittings and to the preparation of specifications for tubing and fittings to be used at temperatures not exceeding 150° F. and at static pressures not in excess of 80 lb/sq. in. Further tests indicated that good results could be obtained both for cold- and hot-water piping, even up to the boiling point of water, and that in the use of the material for potable water supplies there need be no fear of any toxic effect. Last year (January 1943) it was proposed to proceed with a preliminary programme, involving a total of 15,000 dwellings and aiming to save the use of about 1000 tons of steel and some 120,000 metal fittings. Further information will doubtless be available in due course.

147. Flushing pipes, waste and soil pipes, and sparge pipes might be made in plastics. The Ministry of Works has one or two extruded phenolic wash-basin waste pipes under observation. It is said that extruded phenolic mouldings have been tried as gutters with satisfactory results.

148. It will be apparent from these remarks that the use of plastics for plumbing is in an early stage of development. If plastics are to be used for this purpose in the post-war building programme, it will be essential to initiate trials without delay in order to acquire experience in their manipulation and knowledge of their behaviour in use.

149. Plastics tubing has not been much used for gas supply pipes, but it is worth recording that laminated plastics tubing has been successfully used for gas mains in circumstances where metals had previously been found to be subject to serious electrolytic corrosion.

150. Plastics tubing promises to be useful as conduit for bare or insulated electric wiring. Metal screening can be incorporated in the course of manufacture. It is understood that plastics tubing is already being used in Germany to accommodate bare electric wiring in domestic and industrial buildings, this method of wiring being subject to specification (VDE. 0288).

4. APPLIED FINISHES

151. The adaptation of synthetic resins to the preparation of paint compositions has produced new types having quick-drying properties giving hard-gloss finishes of outstanding durability. One of the great advantages is that the composition can be standardised and adjusted to suit the preparation of various types of paint and enamel finish, ensuring a degree of uniformity in the finished product that is unattainable with natural resins. Synthetic finishes can be used on any surface either interior or exterior where a durable painted finish is required. Heat-resisting paints for radiators and heating panels are usually based on synthetic resins. As with all other paints, the surfaces to be painted should be prepared and primed in the appropriate manner described in the Report of the Committee on the Painting of Buildings.

152. Cellulose lacquers and enamels fall into a different category. These consist essentially of a cellulose ester, usually cellulose nitrate, dissolved in an organic solvent, together with suitable resins to give gloss and adhesion, and plasticisers to give elasticity. They have very quick drying properties, but they dry solely by evaporation of the solvent used and remain soluble in the solvent. Consequently, application by brushing is difficult, and they are usually applied by spraying. These difficulties can be reduced by careful adjustment of the solvents, though the brushing technique is rather different from that normally employed in painting, and experience is necessary to obtain successful results on large surfaces. Cellulose finishes are commonly used for painting vehicles and for finishing mass-produced furniture and toys. While their use for general decorative work is attractive, especially as interior finishes in hotels and business premises, where time is an important factor, there are difficulties to overcome before they can be considered eminently suitable for the purpose, for example, good ventilation is needed to remove solvent fumes.

5. MISCELLANEOUS USES

153. Plastics have been put to a number of other building uses to which brief reference may be made.

CONCRETE SHUTTERING

154. Resin-bonded or resin-faced plywood, laminated plastics and hardboard can be used as removable linings to concrete shuttering to produce concrete surfaces of good appearance. With careful treatment the sheets can be used repeatedly.

155. Insulating board is commonly used as permanent shuttering, the sheet being loosely fixed in the forms so that it bonds with the concrete and remains in position when the forms are removed. Used in this way it improves the thermal insulation, eliminates the worst effects of condensation and serves as a base for plaster. Hardboard is used in the same way. It has been suggested in the patent literature that plastics sheets might be used in a similar manner, employing some form of mechanical key to ensure good adhesion, and that such sheets fixed in suitable positions to structural members would carry some of the structural stresses and act as reinforcement to the concrete. In view of the limited mechanical properties of plastics, it is doubtful if this would be so. But, employed simply as a facing, a plastics sheet backed with insulating board would produce a satisfactory bond, would give the desired thermal insulation, and would need no further decoration. Synthetic glues might be used to glue sheet materials directly to brickwork or plaster, but although this method is dealt with in some of the trade literature, it is not known whether there has been any considerable experience in its use.

ACOUSTICAL CONTROL

156. Sheet materials of all kinds can be used for acoustical control in auditoria and offices.

157. Insulating board has been widely used as a sound absorbent. Besides the sheet form, perforated tiles are manufactured specifically for this purpose. The board is also used in special forms of construction to minimise annoyance caused by air- and structure-borne noises and as an underlay for carpets and linoleum. The makers issue detailed technical information on these applications.

158. Low-density acoustic materials owe their sound-absorbing properties to their porous texture. This property is not present in the other types of sheet material dealt with in this Report and is lost from the low-density type if a wear-resistant surface is superimposed. But sound control can also be achieved by using "panel absorbents" in which the sound absorption arises mainly from the vibration

of the material. A high degree of porosity and resilience in the material is not then an essential requirement.

159. By virtue of their porosity, low-density fibreboards absorb sound over the middle and higher range of audible frequencies. The frequency can be extended into the low-frequency range by mounting panels with an air space between the wall and the board. Low-frequency absorption is difficult to obtain in any other way. The degree of absorption and the frequency range, over which the absorption is effective, vary with the thickness of the air space. The efficiency can be improved by fixing felt or other soft absorbent round the edges of the air space. With the less porous membranes, low-frequency absorption can be similarly obtained by suitable mounting. Furthermore, the provision of holes or slits in the sheet extends the absorption over the middle and higher frequencies so that, by proper choice of perforations and method of mounting, it may be possible to use panel absorbents to give uniform absorption over the whole range of audible frequencies.

COVERINGS FOR METALS

160. Cellulose acetate and other thermoplastics are used as coverings to wood and metal articles, particularly door furniture and hand rails, giving surfaces that are warm to the touch, resistant to corrosion and easily cleaned.

STAIR AND ESCALATOR TREADS

161. Stair and escalator treads have been made in plastics and are reported to have been very satisfactory in use.

WALL TILES

162. Light-weight, decorative tiles have been made in transparent or translucent polystyrene plastics for use in artificial lighting schemes or for borrowed lights.

FLOORING AND RENDERING

163. Synthetic resin compositions have been used for jointless flooring and in place of mortar as external rendering on brickwork. Flooring tiles have been made in vinyl plastics. Special plastics products are made for heavy-duty factory flooring.

ACID TANKS

164. Cold-setting phenolic resins are used to build acid-resisting tanks for use in industry and as mortar for tacks in brickwork.

HINGES

165. In the United States and in Germany door hinges have been made in moulded laminated plastics. Piano-type hinges in cellulose acetate made by extrusion are available in the United States. They are lighter than metal hinges and can be fixed with screws, rivets or adhesives. It is said that they are strong enough to be suitable for use in articles of relatively heavy construction.

PROTECTION OF PIPES IN CORROSIVE SOILS

166. Cellulose plastics in the form of flexible film have been used for wrapping pipes laid in corrosive soils and are reported to have provided effective protection.

PILE-DRIVER DOLLIES

167. A small but interesting application is the use of blocks of laminated fabric plastics as pile-driver dollies. These have been found to have a much greater endurance than those of wood and to allow the work to proceed at a pace that would cause a wooden dolly to catch fire.

FURNITURE AND SOFT FURNISHINGS

168. Besides application as beadings and facings for table-tops, bars and counters, plastics provide sheet materials and extruded sections for the manufacture of furniture and fabrics for soft furnishings, including upholstery and waterproof curtains. Woven nylon and polyvinylidene chloride monofilaments have been used for insect-proof window screens with excellent results. They are said to provide better vision by reason of the transparency of their constituents.

6. MANIPULATION AND FIXING

MOULDED PLASTICS

169. Moulded plastics are supplied complete with screw holes, lugs and flanges, or other provisions for fixing, and are strengthened with bushings or other metal inserts where necessary. The method of fixing and the moulding material used are chosen by the designer and manufacturer with the object of providing an article that can be fixed easily and with a minimum risk of damage, but neither design nor choice of material can cater for unintelligent handling. Since, unlike most metals, thermosetting plastics do not yield under stress, a moulding may be broken if undue force is used or if the ground is not properly prepared. Reasonable care must be exercised. Plastics are not unique in this respect. Builders are used to handling porcelain or earthenware fittings that need even greater care in fixing.

170. Extruded plastics mouldings, which emerge from the die in continuous lengths, cannot be provided in the course of manufacture with screw holes or attachments for fixing. Extruded curtain rails, skirtings, cover strips and the like need further manipulation either at the works or on the site. The materials cannot as a rule be nailed, but holes can be drilled without difficulty, and screws with plastics-covered heads can be supplied to match.

171. Detailed descriptions of moulded or extruded units for making door and window frames and skirtings together with proposed methods of fixing are to be found in the patent literature.

SHEET PLASTICS

172. Methods of manipulating and fixing sheet plastics depend to some extent on the character of the material in question. Manufacturers are always ready to advise on the best method to be adopted in any particular circumstances.

173. Resin-bonded plywood and the less dense varieties of wood-waste board can be worked with the ordinary tools of a joiner and can be nailed to wood framing or battens in the customary manner.

174. Laminated plastics and similar sheet, on the other hand, are more difficult to work. They are conveniently cut to size and worked with mechanical tools following the instructions issued by the manufacturers, though they can be worked by hand if need be. They cannot be nailed without drilling holes first. The sheets might be moulded to give a flush surface with an overlap at adjacent edges. The design would then be planned to dimensions that permit the use of whole sheets. Unless the fixing nails or screws are to be hidden by cover strips, the holes should be countersunk and screws used to match the sheet. The screws should fit loosely in the holes to allow for slight movement in the sheet or grounds. Plastics cover strips or channelled strips designed to hold the edges of the sheet can be fixed in the same way. Where fixing strips are used, the drilling, nailing or screwing of the sheet itself are, of course, eliminated. There are available numerous fixing devices designed to hold sheet material to steel framing and to make roof linings, walls and partitions; and there is at least one system using adjustable steel framing to take the place of wood studs or battens.

175. The spacing chosen for the grounds depends on the rigidity of the sheet, and, because all the edges need support whatever the material used, the spacing must also be guided by the width and length of the sheet. Before the grounds are fixed the walls should be given opportunity to dry and the timber grounds should be conditioned to an appropriate moisture content. Timber grounds and the backs of plywood sheets fixed to external walls should be coated with red lead or bituminous paint and provision for ventilation should be made at the top and bottom of the cavity. Wood-waste boards should presumably be treated in the same way, though there has as yet been little practical experience in their use. Laminated plastics, being more resistant to moisture and not subject to attack by fungi, do not need protection in this manner. Plywood, veneered with laminated sheet, is usually faced on both sides to avoid the distortion that might occur in a sheet of unbalanced construction, so that here again treatment of the back of the sheet is not called for.

176. Some of the sheet materials dealt with can be moulded in the manufacturing process to any desired simple or compound curvatures. This would not be practicable unless large numbers of similar shape were needed. Alternatively, flat panels can be bent to simple curves, choosing the thickness of the sheet according to the flexibility of the material and the radius of curvature required. Wood-waste boards as made at present would be hardly suitable for this purpose. Resin-bonded plywood can be steamed or soaked in water and bent across the grain of the outer veneers. For curves of small radius veneers backed with canvas can be used. Thicker plywood can be bent by saw-kerfing the back. If properly done the sheet can be bent to practically any radius without undue risk of fracture, but the saw-kerfs are apt to show in course of time.

TUBES AND PIPES

177. Use of thermoplastics tubes involves no great difficulty in installation, but operatives would need to be trained. The pipes can be softened by warming and be bent to shape on the site. Joints can be made by flaring the ends, which can be welded or cemented, or, more simply, by holding the squared ends against a hot plate until they soften and pressing them together. Moulded screw fittings can also be used.

178. Thermosetting plastics tubes cannot be bent to shape, but extruded tubes can be manufactured in prefabricated bends limited to a radius of not less than fifteen times the diameter of the tube; laminated tubes could be moulded to smaller radii. Laminated tubes can be threaded with standard equipment (with suitable modification of the cutting angle) to make screwed joints. Fabrication using cemented joints may possibly be facilitated by the recent development of glues designed for use with thermosetting plastics.

TRAINING OF OPERATIVES

179. While there has been a fair amount of experience in the building industry in the fixing of plastics sheet materials, the fixing of tubing in plastics is a comparatively new art and there are at present few operatives with the necessary knowledge and experience. Steps will have to be taken to provide training if plastics are to find any widespread application in this direction. In Germany, before the war, courses were instituted in which training lasting several months was given in methods of jointing and fixing plastics tubing. No such steps have yet been taken in this country.

180. There has been a suggestion that there should be a new type of craftsman, a "plastics fixer," who would handle all kinds of plastics products. While there is everything to be said for the view that operatives should know what plastics are and be trained in their use, it is doubtful if there is need for a specialist craftsman

trained to use plastics and nothing else. The versatility of plastics is such that the products of the industry already serve the needs of many different types of operative - electricians, joiners, plumbers, glaziers, painters, flooring specialists and so on. There would seem to be no more reason for having a specialist to fix plumbing in plastics than to have separate craftsmen to handle lead and copper. Plywood, fibreboard, asbestos cement sheet and plasterboard are handled without difficulty. If there is any difficulty in handling laminated plastics it is only for lack of training and experience. The logical course, especially at the present stage of development in the application of plastics to building, would seem to be to include instruction on plastics and their manipulation in the curricula of the technical schools. A course in plumbing would then include instruction in jointing and fixing plastics and a joinery course would include instruction in handling sheet plastics. Plastics are being used for handcraft instruction in certain schools and some technical schools already devote attention to plastics. Extension to all technical schools would familiarise building operatives with the materials, their uses, and their manipulation.

7. LONG-TERM USES

181. The Committee was asked to consider post-war applications of plastics to building in respect of a short-term period of about five years after the end of hostilities and over a longer term. It is, however, difficult to forecast the trend of development far ahead. Intense interest is being displayed all over the world in organic compounds that hold promise of development as plastics. Announcement of the discovery of a new product is immediately followed by investigation of its possible applications. Nylon is a recent and outstanding example. The course of development in plastics over the past few years is enough to show that it would be rash to think that the last word has been said on any application or to attempt to predict what inventions may be introduced or what developments there may be in the next quarter of a century. However, those in the industry may be thought to be in a favourable position to give some indication of expected trends.

182. REINFORCEMENT OF PLASTICS. While moulded and laminated plastics other than resin-bonded plywood, are not at present suitable for use as load-bearing members, it may be that combining alternately paper or fabric base laminated plastics with wood veneers will minimise the effects of lack of ductility. It is unlikely that this disadvantage will be eliminated in the plastics materials themselves, because the molecular structure of thermosetting plastics, the only ones that can be considered for structural uses, are not compatible with the property of ductility. There may be development in metal-reinforced plastics, a field that has been comparatively little explored.

183. ELECTRONIC HEATING. The high pressures required to ensure adequate flow in the mould and the slow rate of diffusion of heat to the centre of the moulding have both imposed restrictions on the size of moulding that could be produced. There are already some developments in performing methods which reduce the need for very high pressures, and electronic methods of heating are now being applied which are independent of thermal diffusion, allowing large mouldings to be heated quickly and uniformly to the curing temperature and substantially reducing the moulding pressures required. These developments may be expected to extend the scope of plastics moulding processes.

184. TREND IN PRICE OF PLASTICS. Considerations of cost are important. The future cost of plastics cannot be closely estimated, but the trend is almost certain to be downwards, particularly if a few good uses were found in the building industry to absorb a large and steady output. The fall in price of polyvinyl chloride composition for the extrusion of flexible tubing from 5*s*. to about 2*s*. 9*d*. per lb.

between 1939 and 1943 illustrates the effect of increased output and technical development.

185. Phenolic moulding powders and cellulose acetate are much cheaper than they were years ago and are now more or less stabilised by the cost of the raw materials. However, the cost of coal-tar products may conceivably be reduced if steps are taken to extract the valuable chemical products from coal on a large scale before using it as fuel. The cost of polythene is likely to fall as further knowledge of the technique of polymerising ethylene is acquired, and would certainly decrease if a source of cheap ethylene were provided in the United Kingdom.

186. RESEARCH. Consideration of long-term uses for plastics is bound up with plans for research. There is insufficient information on such properties as creep, fatigue and ageing over long periods, and it is not known to what extent painting or surfacing in the course of manufacture will bring about improvement in durability. It is felt that much fundamental research must be done to form a sure basis for recommendations on new uses for plastics in the building industry. The whole subject is one that demands study over a long period, involving, besides investigation into the properties of the materials, the initiation of practical trials and experiments based on approved designs. There is much to be done on flooring materials and on the manufacture of doors, window frames and stairways, to name but a few applications that are in the early stages of development. It will be understood that few, if any, tools are available for producing moulded articles like experimental window frames in plastics, and in present circumstances it is doubtful if plant capacity is available. Assuming that arrangements can be made for such experimental work to proceed, special plant and moulds, which form a costly item, will be needed. It is essential that all aspects be carefully weighed beforehand. In some other directions, experimental trials can be made using materials that are already produced in the normal course. Manufacturers of plastics materials are best able to advise and will co-operate closely in studying any new ideas submitted to them.

PART III. DESIGN AND STANDARDISATION

187. A list of British Standard and other specifications relating to plastics materials and products is given in Appendix III. The list will need to be supplemented by the preparation of specifications for other materials. Some attention has already been given by the British Plastics Federation to the question of standardisation of urea plastics.

188. SPECIFICATIONS. The specifications relating to sheet materials incorporate tests on the material in the form in which it reaches the user. With mouldings, on the other hand, the specification (*B.S.* 771) is based on tests on the moulding materials and on mouldings of standardised form. It safeguards the user against defects arising from the use of unsuitable materials but affords no safeguard against defects arising from poor design. It would be possible to prepare standard utility designs and specifications for a range of moulded builders' fittings, as has indeed been done for a variety of articles of equipment supplied for use in the Services, and, if necessary, to draw up performance tests to be met by such standard articles. But even this is not enough, because it is inconceivable that plastics design should be so restricted. The Hall Mark Scheme which is being drawn up by the British Plastics Federation in collaboration with the British Standards Institution is intended to meet this difficulty. The granting of the Federation's Hall Mark will imply that, in the opinion of the Federation and the British Standards Institution, the design and manufacture of the article in question are such that there should be no reasonable cause for dissatisfaction with its performance.

189. Existing specifications for synthetic resin-bonded sheet materials have been drawn up with particular reference to electrical and engineering uses. The requirements are not necessarily the same as those needed for general building uses. Review from this point of view will be required. Specifications for other classes of material will be required.

190. A War Emergency Specification, *Fibre Board for General Building Purposes* (*B.S.* 1142-1943), has recently been published. It will apply only for the period of the war, and will need to be replaced by a revised specification for post-war use.

191. STANDARDISATION OF SIZES. Standardisation of sizes of sheets, rods and tubes for building purposes will also need to be dealt with. From the building point of view, sheet plastics especially are made in an unnecessarily diverse range of sizes. It will not be possible to make any immediate change in manufacturing equipment to produce all types of sheet materials for building use in a limited range of standard sizes, but by consultation between representatives of the building, electrical and transport industries (including shipbuilding), all of which take a share of the present output, it should be possible to draw up a list of preferred sizes to guide manufacturers in their choice when installing new plant and equipment so that eventually these sizes would become standard sizes.

192. CODES OF PRACTICE. There are at present no Codes of Practice relating to the use of plastics in building, though individual manufacturers issue instructions on the manipulation of their products. The possible preparation of suitable Codes of Practice of national application could with advantage be discussed with the Codes of Practice Committee.

PART IV. CONCLUSIONS AND RECOMMENDATIONS

193. Having considered the application of plastics to building in its varied aspects, the principal conclusions to which the Committee's survey has led and the recommendations that can be formulated may now be presented in a summarised form. A summary of building applications is given for ease of reference in Appendix I. Some of the more recent developments in plastics technique have applied to war production, but details have not yet been published. It may be that some can be adapted to the manufacture of materials and components for building, but these are matters on which the Committee as a body is not fully informed. Their consideration must await the time when they can be freely discussed.

CONCLUSIONS

194. (1) PLASTICS IN THE BUILDING INDUSTRY. The plastics industry has in the past shown enterprise and progress in supplying materials and finished articles to meet the needs of the building industry and is capable of making a useful contribution to the expected post-war demand for building materials.

195. (2) RAW MATERIALS. Some of the chief raw materials of the plastics industry depend on by-products from coal distillation. It is understood that steps are being taken to extend the field of research on coal utilisation which, it may be hoped, will lead to a more efficient use of the country's coal resources and the release of by-products for industrial use. Supplies of certain other raw materials depend on the chemical industry and chemical engineering. Some such as cotton linters and solvents not produced in this country are dependent on imports from abroad. (Paragraphs 13, 14 and 15.)

196. (3) CAPACITY OF THE PLASTICS INDUSTRY. The volume of production of plastics has been much increased to meet demands for war materials. Nevertheless, the total volume is small when compared with the production of bricks, steel and cement. Hence there can be no prospect of supplying plastics in very large quantities to compete with the products of these basic industries. (Paragraph 10.)

197. (4) SUITABILITY OF PLASTICS. Plastics are suitable for some building purposes but not for others. They should accordingly be chosen with discrimination to make the best use of the available supplies and to give the greatest measure of satisfaction in use. (Paragraph 4.)

198. (5) LOAD-BEARING MATERIALS. Except for resin-bonded laminated wood, plastics materials in the forms so far available or likely to be available in the immediate post-war period are unsuitable for use as load-bearing structural material. (Paragraphs 88 to 98.)

199. (6) RESIN-BONDED LAMINATED WOOD offers interesting possibilities of development as a structural material.

200. (7) MOULDED FITTINGS. The plastics industry can supply a wide range of moulded fittings for building use. These can be manufactured by mass-production methods. They do not need costly finishing operations and are easy to maintain. They should be carefully designed and the moulding materials should be chosen appropriately. The Hall Mark Scheme promoted by the British Plastics Federation and the British Standards Institution, now being completed, is intended to safeguard the user and maintain the good reputation of plastics mouldings. (Paragraphs 8 and 188; also Appendix III.)

201. (8) SHEET MATERIALS. The plastics industry already supplies a range of different kinds of sheet material for building use. Among these, resin-bonded plywood has proved itself to be suitable for use as an external wall covering even without painting, though painting or oiling is probably advantageous in the long run. Other types of sheet plastics are less suitable for external use, but it is considered that their durability may be capable of improvement. For interior use, laminated plastics offer a wide choice in colour combined with hard-wearing and hygienic qualities, but are comparatively costly unless used as veneers on an inexpensive backing. Matt or satin matt finishes will often be preferred to a glossy finish. (Paragraphs 35 to 70.)

202. (9) COMPOSITE SHEETS. The plastics technique and the development of synthetic resin glues facilitate the manufacture of composite sheet materials. Such materials combining plastics with wood and metal form a useful group of products. The development of composite boards, using low-density materials faced with laminated plastics or wood veneers, offers the prospect of providing sheet building materials having the good surface qualities of plastics, adequate strength and rigidity, and good heat-insulating value. (Paragraphs 59 to 62.)

203. (10) UTILISATION OF WASTE MATERIALS. There is a prospect that, when plant and plastics materials are more freely available, a useful range of building boards will be produced from waste materials (sawdust, flax waste and asbestos waste) bonded with synthetic resins. (Paragraphs 53 and 54.)

204. (11) DIMENSIONAL STABILITY. The dimensional stability of sheet plastics does not, generally speaking, compare unfavourably with the dimensional stability of other building materials in common use. (Paragraphs 108 to 119.)

205. (12) PIPING. The use of plastics tubing offers advantages for certain industrial purposes and in circumstances where metallic corrosion is a serious

problem. Its use for domestic water-supply piping and plumbing is in an early stage of development, and there has as yet been no experience in this country. Practical trials are needed to assess its utility for this purpose. (Paragraphs 144 to 150.)

206. (13) LARGE MOULDINGS. Recent successful developments in the manufacture in plastics of large aircraft components suggest that the processes used might be applied to the manufacture of building components such as staircases. (Paragraphs 47, 134 and 135.)

207. (14) THERMAL INSULATION. The field of utilisation of plastics as heat-insulating materials promises to be extended by the development of light-weight expanded plastics. (Paragraph 70.)

208. (15) TREND OF DEVELOPMENT. The versatility of plastics materials and processes is such that new materials and new applications are continually becoming available. Consequently, it is extremely difficult to forecast what the trend of development will be or how such development will influence the contribution of plastics to building practice. (Paragraph 181.)

RECOMMENDATIONS

209. (1) COLLABORATION BETWEEN BUILDING AND PLASTICS INDUSTRIES. The plastics industry should be encouraged to cater for the needs of the building industry. Not only in the early stages of the development of plastics for building but in all subsequent stages there should be continuous collaboration between the building industry and the plastics industry to ensure that the building uses of plastics are suitably chosen and that the products conform to satisfactory standards of performance.

210. (2) TRAINING. The study of plastics materials and the methods of working them should be included in courses of instruction on building subjects in technical institutions where they do not already form part of the syllabus, so that those engaged in the building industry have opportunity to learn more about plastics and acquire skill in their manipulation. (Paragraphs 179 and 180.)

211. (3) RESEARCH. The following matters might be considered as subjects for research and investigation:

a. Use of resin-bonded laminated wood as a structural material.
b. Development in the manufacture and utilisation of sheet plastics:
   i. Production of composite boards.
   ii. Improvement in durability, including practical trials of paint treatments.
   iii. Methods of moulding edges of sheets to eliminate the need for cover strips.
c. Trials of plastics tubing as piping for domestic use.
d. Manufacture of relatively large building components such as staircases and window frames.

212. (4) STANDARDISATION. The needs of the building, transport and electrical industries should, if possible, be co-ordinated with a view to the eventual standardisation of sizes of sheet materials. Standardisation must necessarily be a gradual process, taking effect as existing machinery and equipment needs to be replaced.

213. (5) Collaborative steps should be taken by the building and plastics industries to establish a range of British Standards relating to the use of plastics materials in building. (Paragraphs 187 to 192.)

H. V. POTTER,
Chairman, on behalf of the Plastics Committee.

APPENDIX I

SOME ACTUAL AND POTENTIAL APPLICATIONS OF PLASTICS OF INTEREST TO THE BUILDING INDUSTRY

HEATING AND VENTILATING

Air filter cells.
Air filter dampers to trunking.
Chimney-pieces.
Coal-fire surrounds.
Electric plugs and sockets.
Electric switches.
Electric fire surrounds.
Fan blades.
Fan housings and air ducts.
Gas-fire surrounds.
Hot-water control valve handles and wheels.
Hot-water radiator grills.
Hot-water radiator shelves (or tops).
Hot-water radiator quadrants.
Hot- and cold-water systems, insulation for.
Humidostat cases.
Punkah type louvres.
Thermal insulation of buildings.
Radiator casings.
Ventilator grills.
Ventilation trunking lining to minimise noise.
Ventilator ducting.

PLUMBING

Bath panels.
Bathroom wall covering and skirting boards.
Bath seats.
Brackets for wash-hand basins.
Chain pull handles.
Cistern ball valves.
Covering for W.C. seats and fittings.
Covering for underground pipes.
Electric immersion heater, parts of.
Floats for cistern valves.
Flush pipes.
Handles and controls for wastes.
Hot- and cold-water pipe systems.
Hot towel rail valve handles.
Knobs and handles, various.
Mixing valve handles.
Press buttons for direct flushing W.Cs.
Pipe boards and pipe covers.
Rain-water pipes and gutters.
Sparge pipes.
Splash backs for wash-hand basins.
Sponge racks.
Spray fittings.
Stoppers for baths and wash-hand basins.
Tap handles.
Tap bodies (upper parts).
Tiles for bathroom walls.
Towel rails.
Thermal insulation of hot- and cold-water tanks.
Waste pipes and soil pipes.
Waste pull handles.
W.C. cisterns.
W.C. seats.

ELECTRICAL EQUIPMENT AND LIGHTING

Bases for electric motors and similar apparatus as a mechanical sound insulator.
Baseboards for electric fires and fittings.
Bowls.
Cable covering.
Component parts of elevators.
Ceiling and wall plates.
Ceiling roses.
Diffusers.
Distribution boxes.
Electric fan parts.
Electric fire surrounds.
Electric immersion heater and cooker parts.
Fuse boxes.
Insulating conduit for surface and sunken wiring.
Insulating varnishes.
Junction boxes.
Lampholders.
Luminous name-plates.
Meter boards.
Meter cases.
Pendants.
Plugs.
Reflectors.
Roof lights; bezels.
Shades.
Sheets for flood-lighting of tables in hospitals.
Sockets.
Strip lights.
Switches.
Switch plates.
Switch panels.
Switch boxes.
Thermostat case.
Transparent and translucent hollow slabs or blocks.
Wall brackets.
Wall-mounting switch boxes, surface or sunken type.
Window glazing.

PLASTICS

GAS INSTALLATIONS

Gas-fire cases.
Gas piping (underground).
Meter cases and parts of meters.
Oven door handles.
Pressure gauge parts.
Remote control switch boxes.
Tap handles.
Thermostat cases.

APPLIED FINISHES

Of the more durable types.

TELECOMMUNICATIONS

Battery vents.
Knobs for terminals.
Microphones.
Switchboard and exchange equipment.
Telegraph and telephone line insulators.
Telephone instruments.
Telephone lead-in insulators.
Terminal (distribution) blocks.
Wet-cell battery boxes.
See also "Electrical Equipment and Lighting."

MECHANICAL INSTALLATIONS

Gears and pinions.
Insulating varnishes for the electrical equipment of elevators, etc.
Lifts: signal devices; panelling for interiors.
Mechanical stoker components.
Vacuum cleaner components and trunking for central installations.
Ventilating fan components.
Refrigerator components.
See also "Electrical Equipment and Lighting."

ACOUSTICS

Sound absorbent for acoustical control in auditoria and offices.

FARM BUILDINGS

The use of resin-bonded plywood for:

Barns. Chicken houses. Cowsheds. Portable sheds. Silos.

REINFORCED CONCRETE

Shuttering, sheets for

GENERAL

Architraves.
Barrel bolts.
Bath panels.
Bathroom wall lining.
Bathroom cabinets.
Bathroom stools.
Beams and arches faced with plywood.
Built-in furniture.
Cases for rim locks and latches.
Ceilings, coverings for
Chimney-pieces.
Counter tops and panelling.
Covered passages and porches.
Cover strips for wall panelling.
Cupboard hooks.
Cupboard knobs.
Curtain rail and door rail parts.
Dado strips.
Decorative wall panelling.
Door handles.
Door numerals.
Doors (flush).
Door trim strips.
Drawers for furniture (built-in).
Drawer pulls and handles.
Draining boards.
Draught excluders.
Escutcheons.
Finger plates.
Flooring materials
Floor clips.
Glazing strips.
Handrail units.
Hat and coat hooks.
Hatches, service.
Ironing boards (built-in)
Joining wooden sections *in situ*.
Joining wood frames in construction of window frames, doors, etc.
Kicking-plates.
Kitchen walling.
Letter-box plates.
Loggias.
Louvres.
Mortice lock striking plates.
Name-plates.
Newel posts.
Panelling: bathrooms, kitchens, bars, reception rooms, etc.
Plate racks.
Picture rails.
Partitioning.
Quadrants.
Roller towel fixtures.

Sash cord pulleys and boxes.
Sash fasteners and handles.
Shelf brackets.
Shelving, liquid cement in construction of.
Sinks.
Skirtings.
Shop counters and fittings.
Slip bolts.
Staircases.
Terrazzo divider strips.
Turn buckles.
Wall panelling.
Wall strips.
Wall tiles.
Window bases.
Window frames.

APPENDIX II. COST OF SHEET MATERIALS

COMPARATIVE COSTS OF WALL LINING MATERIALS PER YARD SUPER

MATERIAL	THICKNESS, INCH	MATERIAL COST (DELIVERED)	COST FIXED	—	REF.
Metal lath and plaster	—	—	4/8	Requires painting or distempering and redecoration every three to five years.	(1)
Plasterboard	¼	1/7	3/2	Ditto	,,
Ditto	⅜	1/9	3/4	Ditto	,,
Ditto	½	2/3	4/1	Ditto	,,
Plasterboard (⅜ in.) plastered	½	—	4/–	Ditto	,,
Insulating board	⅜	2/2⅝	3/9	Ditto	,,
Asbestos cement sheet	1/16	1/5½	3/11	Ditto	,,
Ditto	¼	2/1¼	4/9	Ditto	,,
Hardboard	⅛	2/10½ (4)	7/2 (5)	Ditto	,,
Ditto	1/16	4/10½ (4)	8/6 (5)	Ditto	,,
Laminated plastics sheet (at 1*s.* 2*d.* per lb.)	⅛	9/6	14/6 (5)	Painting and redecoration not required.	
Laminated plastics sheet (decorative grades up to 8*s.* per lb.)	⅛	13/6–65/–	19/6–83/– (5)	Ditto	
Laminated sheet veneered on plywood	¼	28/6–37/6 (3)	37/6–48/6 (5)	Ditto	
Laminated sheet veneered on hardboard	¼	26/3–35/3	35/3–46/3	Ditto	(2)
Polished marble	¾	—	60/–77/–	Ditto	,,
Reconstructed marble	—	28/6–35/3	37/6–44/3	Ditto	,,
Terrazzo wall linings:					
In situ	—	—	15/6–20/–	Ditto	,,
Precast slabs	—	—	25/6–36/–	Ditto	,,
Vitreous wall linings	—	—	16/6–45/–	Ditto	(3)
Glazed tiling:					
Plain white 6″×6″	⅜	8/8–12/6	13/5–21/–	Ditto	(2)
Ditto 4″×4″	⅜	12/–14/–	16/9–26/3	Ditto	,,
Decorative	⅜	18/9–25/6	23/6–37/9	Ditto	,,
Oak panelling	—	—	31/6 (2)–90/–	Ditto	

Note. Painting and distempering costs required periodically for the first ten items in this table are: prepare and twice distemper, 8*d.* per yard super; prepare, prime and paint (two coats), 1*s.* 6½*d.* per yard super. (1)

REFERENCES:

(1) *Standard Schedule of Prices* (Ministry of Works and Buildings), January 1942, and Supplement, July 1942.
(2) Laxton's *Builder's Price Book*, 1940.
(3) Specification 1938.
(4) *National Stock Hardboards* (September 1942).
(5) Estimated cost, including supplying and fixing cover strips, allowing 10 per cent. waste, 10 per cent. profit and establishment charges.

APPENDIX III. LIST OF SPECIFICATIONS

The appended table, which is not exhaustive, has been drawn up to indicate what has already been achieved in the direction of preparing specifications for plastics. Many of these do not apply directly to building applications, but they should be taken into account when drawing up specifications for particular building uses. Specifications for moulding materials are applicable irrespective of the purpose for which the finished article is to be used.

There are certain other British Standards, either completed or in course of preparation, concerned with non-metallic ducts for electrical services, doors and windows, flushing cisterns, wall-ties, etc., which are not included in the list, but which should be referred to when the use of plastics for these purposes is contemplated.

British Standards

316–1929. Synthetic Resin Varnish Paper Boards and Tubes for General Electrical Purposes. (Under revision.)

474–1932. Synthetic Resins (Phenol Formaldehyde) for Manufacture of Boards, Tubes and Cylinders.

488–1933. Moulded Insulating Materials suitable for Accessories for General Electric Installations. (Under revision.)

547–1934. Synthetic Resin-bonded Paper Sheets (Grade 1) for Electrical Purposes. (Under revision.)

231–1936. Pressboard for Electrical Purposes.

668–1936. Laminated Synthetic Resin-bonded Sheet (Fabric Base) for use as Gear Material.

771–1938. Synthetic Resin (Phenolic) Moulding Materials and Mouldings. (Amended 1943—admitting use of Avery Impact Testing Machine.)

7–1939. Rubber Insulated Cables and Flexible Cords for Electric Power and Lighting. (Amended June 1943 to include Polyvinyl Chloride.)

972–1941. Synthetic Resin-bonded Fabric Sheet for Electrical and Mechanical Purposes.

1142–1943. Fibre Building Board for General Building Purposes.

British Standards for Aircraft Materials and Components

2D8. Nitrocellulose Syrup.
2D50. Cellulose Acetate.
F56. Transparent Sheets for Observation Panels.
4V2. Casein Glue for Aircraft Purposes.
6V3. High Strength Plywood for Aircraft.

British Standards under Revision or in Preparation, 1943

— Polyvinyl Chloride Compound (PVC) Insulated Cables.
— Cellulose Acetate Moulding Powder.
488–1933. Moulded Materials for General Electrical Accessories. (Draft circulated for comment.)
— Moulded Materials for High-tension Ignition Equipment of Aircraft.
— Moulded Materials for Switch and Control Gear.
— Moulded Materials for use at High Temperatures.
— Moulded Materials for use at Radio Frequencies.
316–1929. Synthetic Resin Laminated Paper Boards.
547–1934. Synthetic Resin-bonded Paper Sheets (Grade 1) for Electrical Purposes.
— Tests on Finished Mouldings.
— Plywood.
— Plywood—Water Resisting.
— Methods of Analysis of Casein. (In abeyance.)
647–1938. Tests for Glues.
— Bleached Lac. (Draft circulated for comment.)

APPENDICES

Ministry of Supply Specifications

Chemical Specifications relating to a range of plastics products have been drawn up by the Chief Chemical Inspector, Ministry of Supply. Details of these are not available for publication.

Ministry of Aircraft Production: Material Specifications, DTD Series

216A. Synthetic Resin-bonded Fabric Mouldings for Magneto Gear Wheels.
315. Pigmented Cellulose Acetate Sheets.
320. L.T. Varnished Insulating Tubing.
339A. Transparent Synthetic Resin Sheets and Mouldings.
383. Cellulose Sheet for use as a Protective Wrapping.
442. Laminated Synthetic Resin-bonded Mouldings.
451. Synthetic Resin (Phenolic) Moulding Materials and Mouldings (Poor Shock Resistance).
452. Synthetic Resin (Phenolic) Moulding Materials and Mouldings (Low Shock Resistance).
453. Synthetic Resin (Phenolic) Moulding Materials (Medium Shock Resistance).
454. Synthetic Resin (Phenolic) Moulding Materials and Mouldings (High Shock Resistance).
496. Insulating Material (Grade " A ") for Mouldings in Aircraft Electrical Accessories.
497. Insulating Material (Grade " B ") for Impact Resisting Mouldings in Aircraft Electrical Accessories.
513. Insulating Material (Grade " K ") for Medium Impact Resisting Mouldings in Aircraft Electrical Accessories and Instruments.
522. Insulating Material (Grade " E ") for Impact and Acid Resisting Mouldings for Aircraft Accumulator Covers.
103. Cellulose Lacquers for Wooden Airscrews.
426. Ethyl Cellulose.
481. Nylon Cordage.
514. Nylon Yarn.
218. Safety Glass for Windscreens.
335A. Synthetic Resin Cement (non-Gap-filling).
402A. Bullet Proof Safety Glass for Windscreen Panels.
484. Synthetic Resin Cement (Gap-filling).
63A. Cellulose Enamels and Primer (for Metals and Timber).
308. Matt Cellulose Finishes and Primer.
517. Matt Pigmented Synthetic Resin Primer and Finish (quick drying).
557. Flexible Paints.
399. Enamels Resistant to Hydraulic Fluids.
400. Petrol-resisting Paint.
370. Laminated Compressed Wood.
427. Plywood for Lightly Stressed Parts of Aircraft.

Government Department Electrical Specification

18–1943. Polyvinyl Chloride Compound:
No. 1001 for sheathing of electric cables.
No. 1002 for insulating conductors of electrical cables.
No. 1003 for insulating conductors of communication cables.

D.F.W. Standard Specification for Electrical and Mechanical Services

12–1936 (Amended 1940). Electric Light and Bell Fittings.
(This specification requires or permits the use of plastics for certain purposes, but does not specify the properties required except by reference to relevant British Standard or Government Department Specifications.)

Post Office Engineering Department Specifications

M102. Synthetic Resin Phenolic and Cresylic Moulding Materials.
S116. Telephone Mouldings.
CW105. Wire Flame-proof Plastic Insulated.
M402. Sleevings, flexible.

GLOSSARY OF TERMS

Contained in this Report are a number of terms used in the plastics industry which may not be fully understood by those not connected with the industry. It was therefore thought desirable to include a glossary.

ACCELERATOR : A chemical compound used with certain types of synthetic glues or cements to provide a choice of setting speeds either at normal temperatures or at higher temperatures.

ANILINE FORMALDEHYDE PLASTIC : A thermosetting plastic produced by the reaction between aniline and formaldehyde.

BENZYL CELLULOSE : A thermoplastic produced by the action of benzyl chloride on cellulose fibres.

BITUMEN : A naturally occurring thermoplastic hydrocarbon complex.

CASEIN PLASTICS : A thermoplastic prepared by precipitation from skimmed milk by very dilute mineral acids and hardened by treatment with formaldehyde.

CAST RESIN : Moulded articles (usually ornamental) produced by a casting process.

CELLULOSE ACETATE : A thermoplastic produced by the action of acetic anhydride on cellulose fibres.

CELLULOSE BUTYRATE : A thermoplastic produced by the action of butyric anhydride on cotton linters.

CELLULOSE NITRATE : A thermoplastic produced by the action of nitric acid on cellulose fibres (usually cotton linters). Examples are celluloid and collodion.

COLD FLOW : Plastic deformation under continuous stress, the rate of deformation being constant.

COMPRESSION MOULDING : The process of manufacture of a moulded article in which the moulding material is loaded into an open mould which is then closed under hydraulic pressure. A moulded article made by this process. Both thermosetting and thermoplastic materials are compression moulded.

CREEP : Plastic deformation under continuous stress, the rate of deformation changing with time.

CRESOL FORMALDEHYDE PLASTIC : A thermosetting plastic made from cresol and formaldehyde.

" CURE " : A term borrowed from the rubber industry to describe the hardening process in thermosetting plastics.

ELECTRONIC HEATING : Heating of a dielectric by means of a high-frequency current.

ETHYL CELLULOSE : A thermoplastic produced by the action of ethyl chloride on cellulose fibres after treatment with caustic soda.

EXPANDED PLASTICS : Solid plastic material treated to produce very light-weight material of cellular structure.

EXTRUDED PLASTICS : Plastics materials formed into strips, beading, rods, tubes, picture rails, etc., by extrusion through a die.

FILLERS : Loading material introduced in the raw plastic to increase the strength of the finished article, or to give to a finished article some specific property. Examples are wood-flour, paper, fabric, etc.

FILM GLUE : Paper impregnated with a synthetic resin for interleaving with wood veneers in the manufacture of plywood.

FLASH : Surplus material which exudes from the closing mould in the form of a thin film. It is easily detached from the moulding by mechanical means, *e.g.* buffing, filing or scraping.

GAP-FILLING GLUES : A synthetic glue of a type which can fill the gap between uneven surfaces of wood.

GLYCEROL PHTHALIC ANHYDRIDE PLASTIC : A thermosetting plastic produced by the reaction between glycerine and phthalic anhydride.

HARDENER : *See* Accelerator.

INJECTION MOULDING : The process of moulding in a hydraulic press with a horizontal ram in which the moulding material contained in a heated chamber becomes soft or plastic and is then forced through an orifice into a closed mould. The mould is cooled down and the mouldings ejected or extracted. A moulded article made by this process.

IMPREGNATED PAPER ; IMPREGNATED FABRIC : Paper or fabric impregnated with a synthetic resin to be used for making laminated plastics.

IMPROVED WOOD : Wood which has been impregnated with a synthetic resin and pressed hot to densify it. It may be of laminated structure.

LAMINATED PLASTICS : Sheet or mouldings having a laminated structure produced by pressing together sheets of impregnated paper or fabric between the heated platens of a hydraulic press or in a mould. Rods, tubes and bars produced by forming impregnated paper or fabric on mandrels and pressing between heated rollers or in a heated mould. Mainly phenolic and urea plastics.

LAMINATED WOOD : Blocks, sheets or shaped members built up with veneers which have been glued with a synthetic resin.

MELAMINE FORMALDEHYDE PLASTIC : A plastic produced by the reaction between melamine and formaldehyde which may be thermosetting or thermoplastic according to the conditions of preparation.

METHYL CELLULOSE : A thermoplastic produced by the action of methyl chloride on cellulose fibres.

METHYL METHACRYLATE : A thermoplastic produced by the reaction between hydrocyanic acid, acetone and methyl alcohol in hydrochloric or sulphuric acid.

MODIFIED GLYCEROL PHTHALIC ANHYDRIDE RESIN : Glycerol phthalic anhydride resin with which is combined, during the process of manufacture, a modifying agent such as a fatty acid, ester gum, etc., to make the resin soluble in drying oils or solvents for paint and varnish manufacture.

MODIFIED PHENOL RESIN : Phenolic resin with which is combined during the process of manufacture a modifying agent such as ester gum, resin, drying oil (tung, linseed), etc., to make the resin soluble in drying oils for paint and varnish manufacture.

MOULDING : a. A moulded article. b. The process of producing mouldings.

MOULDING MATERIAL : Usually powder or flake plastics material which is charged into the mould and pressed or extruded to finished shape.

MOULDED PLASTICS : Finished articles or components which have been moulded from plastics moulding materials by heat and pressure.

NYLON : *See* Polyamides.

PHENOL FORMALDEHYDE PLASTIC : A thermosetting plastic produced by the reaction between phenol and formaldehyde.

PHENOLIC RESINS (100%) : Phenolic resins not containing any modifying agent (to distinguish from " modified phenolic resins ").

PLASTICISER : A non-volatile solvent added to a plastic to act as an internal lubricant to improve the moulding qualities or mechanical properties or both.

PLASTICS : A group of materials which, though stable in use at ordinary temperatures, are plastic at some stage in their manufacture and can be shaped by the application of heat and pressure.

POLYAMIDES : A group of thermoplastics produced from a dibasic acid (*e.g.* adipic acid) and a diamine (*e.g.* hexamethylene diamine). The term " nylon " has been coined to describe this group of plastics.

POLYETHYLENE : A thermoplastic produced by the polymerisation of ethylene.

POLYMERISATION : A chemical change resulting in the formation of a new compound whose molecular weight is a multiple of that of the original substance.

POLYTHENE : A generic name coined to describe polyethylene.

POLYVINYL CHLORIDE : Polymerised vinyl chloride.

PREMIXING PROCESS : Process of mixing a plastics binder with paper- or board-making materials to be subsequently pressed and cured under heat and pressure.

REINFORCING MEDIUM : *See* Fillers.

RESIN-BONDED PLYWOOD : Plywood made by using a synthetic resin glue or film glue binder between the wood veneers.

RESINOUS MATERIALS : Plastics in the manufactured state for working up into finished products by various processes, including resins, moulding materials and liquid cement.

RUBBER BAG MOULDING PROCESS : *See* description given in Report, paragraph 47. Moulding by inflating or exhausting a rubber bag to apply a uniform pressure.

SHELLAC : A thermoplastic resin excreted by the lac insect which feeds on the bark of certain Indian trees.

STYRENE PLASTIC : A thermoplastic produced by the chlorination of ethyl benzene and subsequent removal of the hydrochloric acid. Commercial processes are not yet disclosed.

SYNTHETIC RESIN : A resinoid or resin-like substance produced by chemical synthesis as distinct from a natural resin.

SYNTHETIC RESIN GLUE : A liquid resin, usually phenolic or urea resin, used

for coating the veneers of wood in the manufacture of plywood. Both hot- and cold-setting glues are used. *See* Accelerator.

THERMOPLASTIC : A plastic which, when heated, softens without undergoing chemical change and is therefore capable of being softened repeatedly.

THERMOSETTING PLASTIC : A plastic which, when heated, softens initially but subsequently undergoes chemical change, which process causes it to harden and renders it infusible and insoluble in common solvents.

TRANSFER MOULDING : A method of injection moulding used for thermosetting materials.

TRANSPARENT AND OPAQUE PLASTIC SHEET : Finished sheet available in various sizes and thicknesses made mostly from thermoplastics, but small sheets are made from phenolic plastics (thermosetting).

UNDERCUT : A part of the section of a moulding which prevents it from being withdrawn from the open mould by a single extraction method. Split moulds must be used, the split being at the widest part of the moulding, or the split may be longitudinal in the case of some types of mouldings.

UREA FORMALDEHYDE PLASTIC : A thermosetting plastic made from urea and formaldehyde.

VINYLIDENE CHLORIDE : A thermoplastic polymer of asymmetric dichlorethylene. It can be oriented by drawing or stretching.

VINYL PLASTICS: Thermoplastic materials made from vinyl polymers which in turn are produced from acetylene or ethylene.

VINYL POLYMERS : Polymers of vinyl compounds—vinyl chloride, vinyl acetate, vinyl alcohol, and so on.

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S. Whyte, B.Sc.
E. A. Blanch.

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TERMS OF REFERENCE

To consider present practice and new proposals in the application of plastics to heating and ventilating, lighting, plumbing, electrical, gas, and mechanical installations, painting, internal and external furnishing, building construction, and any other applications which may suggest themselves.

To make recommendations for practice in post-war building; to make such recommendations for further research as may arise after these studies.

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NO. 4

PLUMBING

BY

THE PLUMBING COMMITTEE OF
THE BUILDING RESEARCH BOARD OF THE
DEPARTMENT OF
SCIENTIFIC AND INDUSTRIAL RESEARCH



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The series of Reports being published under the title of Post-War Building Studies owes its origin to a desire expressed by professional and other institutions connected with the building and civil engineering industries to assist and support the Ministry of Works in regard to post-war plans. During the latter part of 1941 the then Minister, in order to take advantage of these offers of assistance which he was receiving from all quarters, encouraged the establishment of a series of Committees to investigate and report on the major problems which were likely to affect peace-time building. He also offered, on behalf of the Ministry, to provide the necessary staff and organization to co-ordinate the various inquiries, in such a way as to avoid duplication of effort and to secure so far as possible uniform direction and policy.

A full list of the Reports which are being issued is given on the back page of the cover.

The Committees were either appointed by a Government Department or convened by a professional institution, a research association or a trade federation, as seemed most appropriate in each case; they were so constituted as to ensure that the Reports contain the considered views of experts and others closely concerned with the subject. The Minister gratefully acknowledges the work of the Committees and the valuable assistance given both by the various convening bodies and by the individual members. The Reports are not official publications in the sense that the Government as such is responsible for or necessarily accepts the views expressed, but their contents are authoritative and cannot but be of great value to all concerned with preparations for building after the war.

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DEPARTMENT OF SCIENTIFIC AND INDUSTRIAL RESEARCH

THE PLUMBING COMMITTEE OF THE BUILDING RESEARCH BOARD

To The Building Research Board.

GENTLEMEN, We, the Plumbing Committee, beg leave to present a report on the inquiries which we were appointed by you in February 1942 to undertake under the following terms of reference:

i. To review existing scientific information and practice in this country and abroad on plumbing (including the underground drainage forming part of normal building works), with particular reference to the supply of cold and hot water in buildings and the removal of soil, rainwater, and waste therefrom.

ii. To make recommendations for practice in post-war building.

iii. To make such recommendations for further research as may suggest themselves in considering (i) and (ii).

MEETINGS OF THE COMMITTEE

We have held twenty-two meetings, in the course of which we have surveyed plumbing practice in this country, studied a number of special problems which seemed to call for our attention, and prepared certain recommendations for plumbing in post-war construction.

SPECIAL CONCERN WITH LOW-COST HOUSING

Bearing in mind the anticipated requirements of the immediate post-war period, we have attended particularly to low-cost housing. Concentration on this type of building in respect of its plumbing layout, materials used for plumbing, and plumbing appliances—has made it impossible to give a balanced treatment to plumbing as a whole, and we have therefore devoted little of the time at our disposal to subjects which did not seem to us to promise such good returns in the form of useful recommendations on our part for immediate post-war use. Examples of such omissions or partial treatments are rainwater disposal from roofs, drainage below ground, and the plumbing of non-domestic buildings. As regards the last item, however, much of what we have had to say about low-cost housing should apply to plumbing generally.

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GLOSSARY

PLUMBING

A REPORT BY A COMMITTEE APPOINTED BY THE BUILDING RESEARCH BOARD OF THE DEPARTMENT OF SCIENTIFIC AND INDUSTRIAL RESEARCH

INTRODUCTION

DEFINITION OF PLUMBING

1. It may not be out of place at the outset to refer briefly to what we have considered to be the scope of our inquiries. The word "plumbing" as a description of a craft or trade is not very well defined. According to the Oxford Dictionary, the plumber is "an artisan who works in lead, zinc, and tin, fitting in, soldering, and repairing water and gas pipes, cisterns, boilers, and the like in buildings; originally a man who dealt and worked in lead." But, rightly or wrongly, the definition according to the ordinary parlance in the industry goes beyond that. For the purpose of this report we have taken the word as covering the provision of water supply from the water undertaking's main to the various washing and sanitary appliances used in domestic buildings, the removal of water and waste matter from appliances * (including the underground drainage forming part of normal building works) and the design of the appliances.

RESULTS OF PRELIMINARY SURVEY

2. Our preliminary survey showed us that there were a number of opportunities for greater efficiency and economy in plumbing practice in this country. Expressed in general terms these opportunities may be said to lie in:

a. Taking greater care in the installation of plumbing systems to remove hazards to health, and also to obviate inefficiency and breakdowns of service, which, besides causing inconvenience and discomfort to users, may lead to costly maintenance and renewals.

b. Securing more uniformity in practice throughout the country so that the work of all concerned with plumbing may be simplified and costs reduced.

c. Extending the standardization of plumbing appliances and fittings.

d. Taking measures for greater economy in construction, including carrying out in the workshop instead of on the site all work which may be dealt with more satisfactorily in the former.

3. In the course of our preliminary survey, and also at subsequent stages in our work, we noted a number of commonly occurring defects in plumbing practice. These have been instructive to us in preparing our recommendations, so we thought it advisable to record a few of them. We have done so in Appendix I.

BY-LAWS

4. At an early stage in our deliberations we discussed the question of by-laws, including the regulations of water undertakings. It was clear to us that more unification of by-laws and regulations was advisable in the interests of greater efficiency and economy. We felt, however, that our work would be hindered rather than helped by undue concern with the by-laws position. Our most important duty was to produce recommendations for improved practice, taking account of economy as well as efficiency, and without thinking too much as to whether the recommendations were in accord or conflicted with existing by-laws. Once a sound basis for improvement had been established in that way and the basis generally accepted, plumbing practice throughout the country would be influenced in the right directions, and the question of by-law revision could be viewed in clearer perspective by the competent authorities.

* See Glossary.

CONSULTATION WITH AUTHORITIES ON PLUMBING MATTERS

5. In order that our findings should be upon a broad basis we consulted, by personal interview or by correspondence, a considerable number of experts in various fields of our subject, including sanitary engineers, plumbers, architects, contractors, housing authorities, manufacturers, and others. One means adopted of obtaining the evidence we needed was to circulate to a number of Institutions, Associations, and other bodies interested in plumbing, an Interim Report, prepared in October 1942. The response to our request for comments on this report was very encouraging. Many valuable suggestions were received which have helped us considerably in formulating conclusions in the present report.

6. We have made a brief study of plumbing practice in America and have been in contact with American technicians on certain points. Opportunity has also been taken to discuss German and mid-European practice with German and other architects now resident in this country.

PLUMBING BASED ON PRACTICE RATHER THAN RESEARCH

7. We felt that the consultation of practical experience over as wide a field as possible was of special importance in view of the nature of our subject. Plumbing in this country has developed almost entirely on a basis of practice and suffers to some extent from the absence of research which might have resolved some of the variations in practice and given confidence for the more rapid introduction of improved methods. This disadvantage has been felt in a number of directions and present circumstances give little opportunity for carrying out a research programme. Any immediate recommendations have, therefore, to be based upon the considered views of experienced men in the industry. Their views would, in any case, be an essential element in any review of practice, but the absence of quantitative data sets a limit to changes that can safely be recommended.

DIFFERENCES OF OPINION ON PLUMBING MATTERS

8. We have found differences of opinion between experts on many plumbing matters. No doubt this is inevitable considering that in a plumbing problem one may be concerned with such diverse factors as hygiene, properties of materials, hydraulics, water supply, plumbing technique, the need for economy, and the general requirements and habits of the user of plumbing services. Our task has been to try to make reasonable recommendations for post-war use, in full realization that it is not possible to satisfy all desiderata at the same time. Safety from the sanitary point of view must take first place in all design for plumbing, but the need for special economy in certain classes of work may place limits on what can be done, for instance, in the way of securing good appearance and the full convenience of the user. Further, certain requirements may be to some extent mutually incompatible. For example, concealed piping pleases the housewife, simplifies cleaning and removes certain possibilities of accidental damage in use; but, on the other hand, visible piping is easier to repair and replace, it reveals leakages at an earlier stage and in some cases it may be safer in frosty weather. It is not surprising that experts, giving different weight to different factors, reach different conclusions as to detailed construction. The important thing is, we feel, to appreciate all the points concerned, to put essentials first and then to make as reasonable a balance as possible of the other requirements in any particular case.

We have tried to deal with this problem by formulating good principles in general terms and then giving examples to show ways in which these principles might work out in a particular case. Paragraph 11 of this Introduction refers to this matter again when describing the form and objective of Parts I and II of our report.

SPECIAL SUBJECTS CALLING FOR ATTENTION

9. Within our general scheme of concentrating on low-cost housing we have paid special attention to certain problems which, from the evidence given to us and from our own observation, seemed to call specially for attention. As already stated in paragraph 3, a few commonly occurring defects have been noted in Appendix I, but brief notes on the following subjects may be appropriate at this stage:

a. *Frost Precautions.* We have attached considerable importance to this subject. Frost precautions are dealt with, chiefly, in Part I.

b. *Planning for Plumbing.* We have been impressed by the need that buildings should, wherever possible, be planned so as to allow good and economical plumbing to be carried out. The location, in a building, of its plumbing equipment, including the washing and sanitary appliances, hot-water heaters, storage cisterns, etc., may have marked effects on the efficiency and cost of plumbing. We feel that many buildings in the past have been designed without sufficient regard to this factor and the plumbing has suffered accordingly. While it is not suggested that the plumbing of a building should be held to be of such relative importance as to control and restrict planning unreasonably, a fair compromise should be effected, bearing in mind the serious inconveniences to building users which may arise from an unsatisfactory plumbing system and the undue costs of installation and upkeep which may be incurred thereby. Early consideration of the layout of the plumbing installation should remove many of the disadvantages which have formerly arisen under this head. The diagrams discussed in Part I will, it is hoped, be of value in giving emphasis to this point and in illustrating in detail the benefits of close grouping of plumbing equipment.

c. *Noise in Plumbing.* We have considered the serious annoyance, and even ill effects on health, of undue noise caused by the operation of plumbing systems—particularly in the case of flats. Trouble may arise in connection with plumbing layout and the use of materials and also in the design of the appliances. These aspects of the problem are considered at appropriate stages in our report. In addition there is the problem of preventing the noises which may arise in a plumbing system from travelling to the various parts of the building through the structure. Your Committee on Acoustics and Sound Insulation of Buildings has been dealing with this matter.

d. *Concealment of Plumbing.* While realizing the advantages, from the point of view of the internal and external appearance of buildings, of concealing plumbing work within walls or ducts, we have had to take account in our recommendations of:

i. The need for safeguards in the event of leakages.
ii. Protection against frost (where pipes are buried in outside walls).
iii. The possible harbouring of vermin behind casings.

These considerations have led us to believe that in certain types of buildings accessibility of piping is essential, even if it means that pipes can be seen. This matter is dealt with in more detail in the appropriate sections of the report.

NO FUNDAMENTAL CHANGES PROPOSED

10. We have studied practices which have been basic to good plumbing in this country for a number of years and have tried to show how these practices may be used, economically, in the plumbing of low-cost houses. To this extent our recommendations are naturally orthodox in character. We have not ignored, however, the possibility that unorthodox methods might profitably be introduced; and, to make sure that opportunities in this direction should not be missed, we have considered a number of suggestions for new or unusual practices. For example, we have examined the possibilities of using a simplified one-pipe system for low-cost

housing. (Appendix II gives an account of our experimental work on some one-pipe installations. Part I includes some recommendations for the use of one-pipe systems in low-cost housing.)

In the main, however, we find it necessary to stress the achievement of efficiency and ultimate economy by good workmanship and suitable materials applied to familiar and orthodox design.

REFERENCE TO PRINCIPLES

11. It has seemed necessary to us to set down the fundamental principles which should be borne in mind by those responsible for designing the layout of plumbing installations and for selecting materials for plumbing purposes and specifying the methods of jointing to be employed. Parts I and II of our report contain a statement of these principles, applying to layout and materials respectively.

Constant reference to sound principles is, we feel, the surest way of maintaining good standards, guiding developments along the right lines and discouraging unwise departures from traditional practice.

Since, however, the implications of a principle are not always readily seen we have thought it advisable to make certain additional recommendations as to how these principles might be interpreted in typical cases. In each case these recommendations follow the statement of the principle to which they apply. They are necessarily of a selective character and may, therefore, be more open to differences of opinion than the principles themselves.

It may be felt in some quarters that it is not necessary to state plumbing principles, on the ground that they are well known in the trade, frequently referred to in the technical press and amply covered by courses of instruction in the technical schools and colleges. When, however, plumbing systems have, in the past, been found to be defective in operation, where stoppages have occurred, where material has corroded or failed under stress, or where unnecessary expenditure has been incurred, it has often been due to ignorance or disregard of rational principles. It seemed to us, therefore, that a restatement of plumbing principles in this report would serve a useful purpose.

THE STANDARDIZATION OF PLUMBING APPLIANCES AND FITTINGS

12. A greater measure of standardization of types and dimensions of plumbing appliances and fittings than obtains at present would facilitate the supply, installation and replacement of components.

At an intermediate stage in our inquiry we recommended that British Standards should be prepared for baths, washbasins, sinks, and water-closet suites for low-cost housing. We also made certain suggestions of a detailed character regarding these appliances. These suggestions were considered by the Standards Committee of the Ministry of Works; and, at their instigation, the British Standards Institution has now formed Committees to carry out this standardization work. After further study of the functions of these plumbing appliances we have prepared fuller recommendations regarding their design. These recommendations are given in Part III of the present report.

As regards the standardization of water-supply fittings, much has already been done, by the Health Departments and the British Waterworks Association, to lay down standards, but effect should be given to the co-ordinated recommendations of these authorities in the country as a whole.

Part V of the report contains a reference to further suggested items for standardization.

OVERALL ECONOMY

13. We have had regard to the possibility that after the war the utmost economy in construction may be required and that the question may then be asked: To what extent can principles be abandoned under the stress of necessity? The answer is that where a principle concerns health, adequate durability of materials,

prevention of damage due to frost, and similar essentials it cannot be abandoned without the likelihood of an eventual expenditure on the part of the community greater, sometimes considerably greater, than the initial saving which might have been made. When carefully examined we think it will be found that not a great number of the principles we have recorded can be ignored without an overall loss to the community on a cash basis alone. We feel it necessary to make this point because it may be found that plumbing installations designed on the basis of the principles in our report may in certain parts be more costly originally than if carried out according to some pre-war practice. On the other hand, we feel that the extension of standardization in plumbing, the carrying out of certain parts of the work in the workshop instead of on the site and other measures recommended in various parts of the report may redress the balance and sometimes result in greater overall economy in first costs.

SUGGESTIONS FOR IMPLEMENTING THE REPORT

14. It should be clearly realized that the proper implementing of our recommendations would mean the general introduction of certain plumbing methods which are not yet permissible in every locality. Proposals to modify local by-laws and regulations, in the interest of greater economy and efficiency in plumbing, should receive sympathetic consideration.

The purpose of our report would also be more readily achieved:

a. If suitable measures were taken to encourage the phrasing of plumbing contracts and the organization of plumbing work so that sound principles, on the lines of those which we have recorded, are followed.

b. If new methods of fabrication, including work off the site, were given every facility for development, in so far as plumbing efficiency is not reduced by such methods.

c. If full use were made of standardized appliances and fittings in connection with specifications for plumbing work.

We have attempted to provide data and to make suggestions throughout the report which could serve to amplify the above proposals with the necessary detail.

FURTHER WORK

15. Some observations on what might be done by experiment and research to resolve certain differences of opinion among plumbing experts and to provide data for a progressive development of plumbing practice are given in Part V.

ACKNOWLEDGMENTS

16. Reference has already been made in paragraph 5 to the advice given to us by experts on all aspects of plumbing. All the comments made to us received careful attention in our discussions and we profited greatly from them. We wish, therefore, to express our gratitude to all those who helped us in this way and to record how much we appreciate the trouble that they have taken to do so and the ready way in which they responded to our request for advice.

We desire to place on record our appreciation of the valuable assistance we have received from the Building Research Station, and in particular from Mr. F. L. Barrow of this Station, who has been responsible for conducting the inquiries associated with the work and without whose indefatigable labour in conducting experiments and drafting documents we could never have completed our task in the time allotted.

PART I. THE LAYOUT OF PLUMBING INSTALLATIONS

Parts I and II consist of principles followed in each case (in smaller type) by recommendations for their application.

17. Our purpose in setting down a number of principles for the layout of plumbing installations has been explained in the Introduction. (See paragraph 11.)

To assist in making some recommendations on the application of these principles we have worked out, and illustrated in the drawings appended to this report, three examples of plumbing installations for low-cost houses. Differing conditions have been chosen for each of these cases so as to cover a range of normal requirements in this type of dwelling. The conditions assumed for the three cases are set out in the following table:

Level of Appliance	Case 1 Terraced House	Case 2 Semi-detached	Case 3 Semi-detached
Roof space	Cistern		
First floor	Basin Bath W.C.	Cistern Basin Bath W.C.	
Ground floor	Sink	W.C Sink	Cistern Basin Bath W.C. Sink

The drawings show only those parts of the house which directly affect the plumbing, but, in preparing them, house plans have been studied to the extent of making reasonably sure that normal planning requirements could be met with the plumbing space occupied as shown.

It should be stressed that these drawings are not meant to serve in any way as rigid plumbing models. They have been prepared simply to illustrate the principles and to observe some of the implications of these principles in practice. It is realized that further analysis could quite possibly lead to improvements in these layouts while maintaining equally well the general principles on which they are based.

18. The principles and applications are grouped under the heads of "Water Supply," "Exclusion of Foul Air from the Building," "Precautions against Vermin Infestation," "Safeguards against Boiler Explosions," "Frost Precautions," "Efficiency from the Standpoint of the User," "Precautions against Noise," "Appearance," "Corrosion and Encrustation," and "Economy." Applications are inset under principles.

WATER SUPPLY

19. Underground piping should be laid at such a depth that it cannot be damaged by frost or other means, and thus, by fracturing, lead to waste and contamination of water by substances in the soil, or by percolation of foul water from leaking drains, cesspools, etc., in the vicinity.

In the drawings service pipes are shown entering at 2 ft. 6 in. below ground level.

20. Storage cisterns should be provided with suitable and close-fitting covers to prevent the entry of dust, insects, vermin, etc.

See covers on storage cisterns. (It may also be noted that one outlet at least from these cisterns is on a side opposite to the inlet to obviate dead water.)

21. Taps should be so located in relation to appliances that back-flow of used water into the supply system cannot take place.

Back-flow may be guarded against by keeping the outlets of taps above the flood rim of the appliance. This is largely a matter of design of baths and washbasins and their fittings, but it affects layout in that piping cannot run to globe taps fixed to the walls of baths if this principle is accepted.

22. At least one tap in each separate dwelling should be supplied directly from the service pipe. If only one such tap is provided it should be in the kitchen.

The drawings show drinking water supply in the kitchen only. With little alteration of piping the cold tap on washbasins could also be supplied from the service pipe.

23. Cold-water pipes serving draw-off taps should be so located as not to be exposed to heating up by being placed too near to hot pipes, tanks, etc.

24. The size of cisterns and tanks, the bore of water pipes and the positions of pipe connections to hot-water tanks should be such that a good supply of both cold and hot water is available at the appliances.

a. 40-gallon hot-water tanks are used.

b. The cold-water cistern is at least equal in capacity to the hot-water tank, thus enabling the full capacity of the tank to be used if the mains pressure fails.

c. Note the pipe sizes shown in the drawings. Some distributing pipes in Cases 2 and 3 are larger than corresponding ones in Case 1, to compensate for lower head from the storage cistern.

d. i. The flow pipe from the boiler enters the hot-water tank at not more than three-quarters of the height of the tank in order to guard, as far as practicable, against reversed circulation.

ii. The flow pipe from the boiler enters at not less than two-thirds of the height of the tank in order that a small supply of adequately hot water shall be available soon after lighting up the boiler. The cold-water inlet from the storage cistern is located low so as to minimize the admixture of cold water with hot.

iii. The design is such as to encourage ready flow from the boiler to the tank, thus maintaining the temperature of the latter as high as possible in relation to that of the former.

iv. The cold feed from the cistern connects to the tank and a separate pipe connects from the bottom of the tank to the bottom of the boiler. This prevents a possible direct cold flow to the boiler which might occur if the cold feed were continuous to the boiler with a T branch to the tank.

EXCLUSION OF FOUL AIR FROM THE BUILDING

25. Disposal piping should be so designed that the water seals in all the traps are maintained under all conditions likely to arise in practice.

Both " one-pipe " and " two-pipe " disposal systems are shown in Cases 1 and 2. Trap seals are 3 in. for one-pipe and 1½ in. for two-pipe. Trap vents are omitted. Some full-scale tests (see Appendix II) have recently been carried out to determine to what extent and in what circumstances the omission of special anti-siphonage venting is justified (from the point of view of loss of seal by siphonage) in simple one-pipe systems for two-storey housing. The one-pipe systems shown for Cases 1 and 2 are based to some extent on the results of these experiments, but they are subject to amendment in the light of further experiments projected. (See Part V.) It is urged that, in view of the limited data on this subject so far available, any one-pipe systems not in accordance with accepted British practice (particularly as regards ventilation of traps) should be subjected to tests before use, pending more comprehensive investigations.

Case 3 is shown on the two-pipe system only. This case does not seem to lend itself to one-pipe treatment because the use of a separate compartment for the closet when all the appliances are on the ground floor makes close grouping difficult.

26. Disposal piping should be so placed in buildings that any leakages or other defects that may appear in course of time will cause as little damage as possible. Special care in this connection should be taken in the use of one-pipe systems, particularly those with internal stacks.

The safe use of one-pipe systems, particularly with internal stacks, depends upon the security of the joints and the quality and durability of the pipes. The external stack system is suggested for use when joints cannot be relied upon to remain gas-tight for the lifetime of the building. (The materials used will have a special importance in this connection.) Possible advantages of the one-pipe over the two-pipe system are (*a*) economy, (*b*) simplicity of erection by an appropriate use of pre-assembly.

27. Where practicable, waste systems should be so designed that accumulations of waste matter are not exposed to the open air in the immediate vicinity of doors, windows or other openings.

a. In the two-pipe systems waste and vent stacks are used in preference to hopper heads for receiving bath and washbasin discharges (Cases 1 and 2).

b. The objection to the use of gullies for sink wastes is appreciated, but they are shown in the one-pipe systems in Cases 1 and 2 for the following reasons :

i. Ease of clearance is provided should a stoppage occur due to the sink waste.

ii. If a stoppage occurs in the section of the drain between the sink connection and a manhole, closet discharges cannot back up into the sink.

iii. If waste water is taken into a rainwater gully it will serve to keep the gully trap filled in dry weather.

iv. In pre-assembled systems working tolerances in fitting may be easier to arrange if only bath, washbasin, and closet on the first floor have to be considered.

v. It may be preferable in some cases, for reasons of planning, to arrange the sink at a considerable distance (in plan) from the bathroom appliances.

c. Where gullies are used the waste discharges into a back inlet.

28. Accumulation of waste matter within the building should be avoided.

This question concerns, in the main, the design of appliances (dealt with in Part III), but note that waste tails are kept short.

29. Vent stacks should be carried to such heights and be so placed that their tops are at a safe distance from openings into buildings.

The need for carrying vent stacks to a sufficient height to prevent foul air from entering openings in buildings is one reason why we do not support the suggestion that rainwater may be taken into soil stacks as a general practice (though there may be special cases where it could be done satisfactorily, and there seems little objection to discharging certain isolated waste appliances into properly constructed rainwater stacks). We note the following paragraphs from Section 40 of the *Public Health Act 1936*:

" 1. No pipe for conveying rainwater from a roof shall be used for the purpose of conveying the soil or drainage from any sanitary convenience.

" 3. No pipe for conveying surface water from any premises shall be permitted to act as a ventilating shaft to any drain or sewer conveying foul water."

And in the Rules of the City of New York State, Rule 64 contains the requirement: " Rainwater leaders must not be used as soil, waste or vent pipes, nor shall any such pipe be used as a leader."

PRECAUTIONS AGAINST VERMIN INFESTATION

30. Plumbing pipes should be so located in buildings and the buildings be so constructed in their vicinity that "dead spaces" which cannot be cleaned, or can only be cleaned with difficulty, are avoided, except when properly built ducts are constructed for the housing of pipes, as in blocks of flats, etc. Where such ducts are provided they should be easily accessible for inspection, working, and repairs, and should incorporate means to prevent rats, etc. from climbing up the ducts from floor to floor.

Where it is impossible to eliminate uncleanable spaces behind appliances—*e.g.* behind baths—properly designed covers should be used.

In the drawings no casings to pipes are used except bath panels, and pipes are kept clear of walls. In the case of multi-storey flats ducts would be recommended.

SAFEGUARDS AGAINST BOILER EXPLOSIONS

31. Layout should be such as to provide adequate safeguards against boiler explosions under the conditions to which the system will be subjected.

a. Expansion, flow, return, and feed pipes are kept well within the building plan as a safeguard against closure by frost. In Case 1, where expansion and feed pipes run in the roof space, they are lagged.

b. The hot-water tanks cannot be emptied from taps on the appliances.

c. Safety valves and drain cocks to boilers are shown.

FROST PRECAUTIONS

32. Water-supply piping, cisterns, and tanks should be so located or so insulated that they are adequately protected against frost.

a. Note interior location of rising service pipe, flow, return, feed, and expansion pipes and storage cisterns and tanks. Where distributing pipes have to run along the inner face of external walls they are supported away from them on clips or pipe boards.

b. In Case 1, in the roof space, lagging of pipes and cistern is shown.

c. In Cases 2 and 3, the storage cistern is placed within the house on first and ground floor respectively.

33. Water-supply systems should be so designed that they can be completely emptied, and convenient provision should be made for carrying out such emptying. (This provision is also useful for easy repairing.)

Pipes fall to taps on appliances or to draw-off taps, drain cocks or drain plugs (falls not shown on drawings). In all three cases a draw-off tap is necessary to drain the rising service pipe, and this tap is placed immediately above the stop valve in the kitchen. Draining points not over appliances are avoided as far as possible; and this leads to both drinking water and cold supply from the cistern being shown at the sink in Case 1. If only one cold tap, supplied from the service pipe, had been provided here, a special draining point would have been necessary at the lowest level of the cold distributing pipe. In Case 2, the same problem does not arise because there is a flushing cistern on the ground floor. In Case 3, drain plugs for both hot and cold distributing pipes are provided.

EFFICIENCY FROM THE STANDPOINT OF THE USER (SPECIAL CONSIDERATIONS)

34. Stop valves should be provided in such positions that the effect of frost bursts if they occur can be minimized, and that repairs can be more readily effected.

Stop valves for these purposes are shown on the drawings.

35. The installation should be so designed that cleaning is facilitated as far as possible.

a. Bath panels are used

b. Pipes are kept clear of walls.

c. Where possible pipes are taken through hot-water tank cupboards.

36. It is recommended that, if there is only one water-closet in a house, it should be in a separate compartment.

37. Piping should be located in buildings so as to be reasonably secure against accidental damage.

a. Absence of casing (except bath panels) avoids danger of nails being driven into pipes through boarding.

b. Square head, not crutch, is shown on boiler drain cocks.

38. Layout should be such that faults, *e.g.* leakages, are likely to be detected by the occupants at an early stage.

a. Warning overflow pipes, of adequate diameter to prevent flooding, and suitably placed, are provided to storage and flushing cisterns.

b. Note position of drain cocks and plugs.

c. Most piping is visible.

39. All parts of a disposal system should be so designed as to minimize the risk of stoppages.

a. 4-in. diameter soil stacks are shown.

b. Pipe bends are of easy radius.

c. No " dead ends " occur.

d. Full bore traps are indicated : we do not recommend the use of special " re-sealing " or " anti-siphonage " traps in these examples, and, in this connection, we would call attention to the following comments made by American investigators (see Bibliography, item 66) on traps and trap siphonage :

" We have given attention to the subject of anti-siphon, non-siphon, or re-sealing traps, as they are called. Practically all traps, except the plain traps already mentioned, may be included in this class. There are many different kinds, many of them patented and more expensive than plain traps. They are supposed to resist siphonage better than plain traps by reason of having a deep seal, a greater area or volume, tortuous passages for the water, projecting lips, partitions, or, in some cases, moving parts. The best of the resealing traps, when clean, resist siphonage more than a plain trap of 2 to 4 in. seal, and this may be the case even when slightly fouled. When more completely fouled, this resistance to siphonage rapidly lessens. Properly designed resealing traps unvented and clean resist back pressure somewhat more than unvented plain traps of the same depth of seal, but the difference is not sufficient to justify their general use without vents. Their greater complexity causes them to clog more quickly than plain traps, and, if clogged, they are less easily cleaned by the householder and cannot be thoroughly cleaned by the usual method of using a force pump or plunger. Lack of standardization of these traps makes replacement more troublesome and expensive. The supposed advantages of a

resealing trap lie in the fact that greater resistance to siphonage makes it possible to omit some of the vent pipes commonly installed, and to use longer horizontal unvented waste pipes and thus secure greater freedom in the location of fixtures. Long unvented horizontal runs, however, are in themselves objectionable.

"As before stated, the efficiency of traps should not be considered alone; plain traps should not be compared with 'resealing traps'; the true comparison is between a drainage system including plain traps and a drainage system including resealing traps. The experiments made by the Bureau of Standards have indicated that simplifications in venting are possible even when plain traps are used. Plain traps have the advantages of economy, simplicity, greater freedom from fouling, and greater ease of cleaning. For these reasons we favour having drainage systems designed on the basis of plain traps rather than on the basis of resealing traps, and are of the opinion that the plain-trap system, with simplified venting, affords ample range in the location of fixtures. Resealing traps should not be accorded any special privilege with respect to venting over plain traps, but their use cannot be prevented by regulation. In short, plain trapping with vents should be the prescribed rule, with resealing traps without vents permitted only under very restricted conditions."

PRECAUTIONS AGAINST NOISE

40. Layout should be such as to reduce the production and transmission of noise as much as possible.

In houses the chief requirement as regards reduction of plumbing noises is to install appliances which operate quietly (see Part III) and to plan the bathrooms and water-closets so that they are as remote from the living rooms as possible.

The part played by plumbing layout, as such, is more limited. For quiet, piping should obviously be confined to the rooms where the appliances are fitted or taken outside the building as directly as practicable. Also plumbing appliances should not be fixed against walls adjacent to living rooms. The piping itself should have easy bends and, where quiet is particularly desired, clips and brackets can be insulated from the pipe by suitable pads.

41. The layout of piping should be designed so as to avoid admixture of air with the water.

When water is being drawn from hot taps there is a tendency for the level of the water in the expansion pipe to be lowered. If it falls to a connection to a hot distributing pipe air may be drawn into the pipe and interrupt the flow. In the drawings it has been arranged that the length of the expansion pipe which contains water above the hot distributing pipe connection is sufficient to render this action unlikely.

The risk of air lock is minimized by sloping pipes continually to the refilling and emptying points and by avoiding U-shaped pipes in the system, except where drain cocks or plugs are situated at the lowest part of the U.

APPEARANCE

42. Regard should be had to the appearance of piping whenever it is exposed to view.

a. Visible piping is unavoidable when other important principles are applied. (See paragraphs 30, 32 and 38.)

b. Bath panels are used.

c. In Case 3, the overflow pipe from the cold-water storage cistern is run at such a height along the wall of the kitchen that it could be hidden by a shelf.

CORROSION AND ENCRUSTATION

43. Piping should be arranged in such a manner as to reduce the chances of encrustation and corrosion.

a. The length, slope, and general run of branch disposal pipes shown in the drawings is such that they should keep reasonably clean in use and thus not give rise to special corrosion effects.

b. It has not been thought necessary in the disposal installations shown to fit anti-siphonage piping for the special purpose of lessening the chances of corrosion.

c. The use of one-pipe systems has the advantage that stacks are kept cleaner by receiving discharges from a number of appliances. In particular, bath wastes help to clear solid matter coming from closets and sinks.

d. Adequate space between external stacks and walls facilitates painting.

ECONOMY

44. In view of the need to put good plumbing within the reach of all sections of the community, to conserve materials (including fuel and water) and to economize in labour, costs should be reduced to the minimum consistent with good sanitation, avoidance of frost troubles, adequate services, and reasonably tidy appearance. It is essential that costs should take account of maintenance as well as installation. Planning to avoid stoppages and to provide easy access should trouble arise from any cause is specially important. Plumbing installations should be designed with a view to reducing the amount of piping and the number of connections as much as possible, to facilitating fabrication off the site (where this leads to economy) and to minimizing the cutting of floors, roofs and walls. It should also allow for ease of access for inspection and repair at all parts and for the clearance of stoppages. Care should be taken to design disposal piping in respect of bore of pipes, falls, connections, etc., so that the system is self-cleansing.

a. One-pipe disposal systems may lead to economies if some pre-assembly of piping units is found to be practicable.

b. Close grouping of appliances shortens pipe runs.

c. Pipes are not run in floors.

d. Maintenance costs have been considered by recommending :

i. 40-gallon hot-water tanks, which should have a longer life in service than, say, 25-gallon tanks, other factors being equal.

ii. One-pipe systems, which may lead to more efficient clearance and thus minimize stoppages.

iii. Readily accessible pipes.

iv. Stop valves in positions convenient for use in repair work.

(See paragraph 39 on the elimination of causes of stoppages in disposal pipes.)

e. Economy in water has been considered. Storage cisterns are shown, also 2-gallon flushing cisterns. (Recommendation for the use of 2-gallon low level flushing cisterns is subject to satisfactory operation of low level flushing cisterns with this quantity of water. Trials are proposed.)

f. Economy in fuel has been considered. Flow and return pipes and hot-water tanks are shown insulated, and flow and return pipes are as short as possible.

PART II. THE USE OF MATERIALS FOR PLUMBING PURPOSES

45. This section of our report consists of some principles for, and some notes on, the selection and use of materials for plumbing purposes. The subject-matter is set out under the main headings of "Effect of Materials on Water," "Durability (General, Corrosion, and Mechanical Strength)," "Nature of Interior of Pipes," "Method of Support," "Economy," "Noise Prevention," "Appearance," "Ease of Cleaning" and "Insulating Materials."

EFFECT OF MATERIALS ON WATER

46. Materials used for pipes, pipe joints, cisterns, tanks, etc., should have no deleterious effect on the water.

Water may be adversely affected by the material of the inner surface of pipes, cisterns, tanks, etc., through which it flows. In general, soft waters are more likely to be affected, but this cannot be taken as a general rule. Each case should be considered on its own merits and reference made to practical experience in the district concerned. Precautions to avoid contamination may be (*a*) selection of materials not likely to give trouble with the water supplied, (*b*) modification of the character of the water, or (*c*) a combination of (*a*) and (*b*). Possible effects of water softening within the building itself should be considered.

DURABILITY—GENERAL

47. Materials used for all parts of plumbing installations should, as far as they are available, be adequately durable, *i.e.* they should, as far as is reasonable, function without permitting leakage of liquids or gases during the expectation of life of a normal building.

a. The conditions to which plumbing pipes are exposed in practice are often very complex, particularly in the case of disposal systems, and, until considerably more data are available, the choice of materials for adequate durability will depend chiefly upon practical experience of what has been satisfactory in the past. The way should not be closed, however, to the introduction of new materials into plumbing or to the use in new ways of the traditional plumbing materials when these would seem to be of benefit. Research into these matters should be encouraged, but the results of research are not likely, alone, to bring about developments of this character in plumbing practice; practical trial under normal service conditions is also essential. Perhaps a good plan would be to regard buildings of a non-domestic character as suitable for innovations as regards plumbing materials. In such buildings the results of a material not being as durable as expected would not be so serious as in housing, and regular inspections and, where necessary, replacements would be more practicable.

b. When materials are being specified for temporary buildings it should be borne in mind that a building is not necessarily temporary because it has been so labelled in the first instance. When a " temporary " building shows obvious defects, *e.g.* roof leaking or walls developing cracks, one may expect steps to be taken to prolong its life, or to demolish it and find alternative accommodation for the tenants. Defects in the plumbing, however, may not be detected until appreciable harm is done, say, by contamination of water supply or underfloor dampness, both of which might result from, for example, corroded piping. It is therefore recommended that short-life plumbing materials should not be used in " temporary " buildings without adequate safeguards.

c. In British Standards for plumbing pipes certain thicknesses have been laid down for different diameters and for various purposes. It is recommended that these specified dimensions should not be departed from without special reasons.

DURABILITY—CORROSION

48. When selecting materials to resist corrosion the following should be taken into account: Type of waste to be carried, character of supply water, corrosion leading to encrustation, use of different metals in the same installation, hot-water effects, alternate wetting and drying, weathering, condensation, materials in which pipes are embedded, special corrosive effects and durability of protective coatings. Notes on these matters follow under appropriate headings.

a. TYPE OF WASTE TO BE CARRIED. Waste may consist of human waste, urine alone, domestic waste, human and domestic waste together or trade waste. In public buildings, schools, etc., where large quantities of urine pass through the pipes, furring rapidly takes place. Such accumulations are sometimes removed by using a chemical solvent which is intended to attack the deposit of uric acid salts but to have no effect on the material of the pipes. Consequently, if it is considered likely that uric acid salts may be deposited to any large extent, the method by which it is intended to remove the deposit should influence the choice of materials.

Grease films in pipes carrying household waste are believed to afford some protection against corrosion, but as yet there seems to be no real evidence of this.

b. CHARACTER OF SUPPLY WATER. The relation between corrosiveness of water and its composition is a complex problem on which a considerable amount of research work has been done. It depends on many variables, *e.g.* acidity, the nature of the various salts in solution, the oxygen and carbon dioxide content. Each case has to be judged on its own merits and specific recommendations can only be made regarding the selection of materials when full data are available. The formation of a protective film or coating, also the character and stability of the film, is particularly important in this connection.

c. CORROSION LEADING TO ENCRUSTATION. A common cause of encrustation is the deposition of solids from temporarily hard water coming out of solution when the water is heated. Such actions are obviously independent of the material of the pipes, but the nature of their inner surfaces may control to some extent the deposition of this solid matter. Besides this, however, there are certain types of corrosion which encourage encrustation. It is therefore possible that encrustation may be greater with some pipe materials than with others even with the same kind of water.

d. USE OF DIFFERENT METALS IN THE SAME INSTALLATION. The use of the same material for cisterns and tanks and the pipes connected to them is an obvious safeguard against electrolytic action between dissimilar metals. One reason for laying all piping to falls is to prevent solid accumulations which may set up electrolytic action. All parts of a plumbing system should be left clean after installation or after repairs (especially cisterns and tanks) so that electrolysis cannot be set up by small particles of metal filings, sand, etc., resting therein. Possibilities of electrolytic action being set up between pipes and pipe clips and between clips and their holding screws should also be noted.

e. EFFECTS OF HOT WATER. Corrosion of pipes, etc. usually proceeds faster when they carry hot water, so that special precautions for such pipes should be taken. The increase in efficiency in hot-water supply systems in recent years has had a tendency to increase corrosion of pipes (in places where heat is a contributing factor in corrosion).

f. ALTERNATE WETTING AND DRYING IN DISPOSAL PIPING. A soil-and-vent stack is exposed to particularly severe conditions because, besides discharging gases and moist air and receiving a slight amount of (soft) rainwater, it also becomes dried from time to time. Any protective effect which waste pipes may enjoy by reason of being lined with grease films is not shared by the vent pipes. Anti-siphonage vent branches and vent stacks are exposed to rather less severe conditions.

Overflow pipes are also subject to wetting and drying because, besides receiving occasional discharges, the air within them must undergo some change in moisture content from time to time.

g. WEATHERING EFFECTS. Pipes on the outside of buildings may have to withstand polluted industrial and seaside atmospheres. Materials unsuitable for such exposure may be safe enough in country air, but it must be remembered that a district may become more industrialized during the lifetime of a building.

h. CONDENSATION. Special conditions in kitchens and bathrooms should be allowed for.

j. MATERIALS IN WHICH PIPES ARE EMBEDDED. Buried pipes may need protective coverings as a safeguard against corrosion in certain types of ground. Ashes, clinker and clay containing sulphates, in particular, should be taken account of in this connection. Materials for pipes should also be reviewed in relation to their behaviour when in contact with lime, concrete, gypsum plasters, "jointless flooring," damp wood, etc.

k. SPECIAL CORROSIVE EFFECTS. Flue gases, cooking fumes, domestic cleaning materials, etc., should be considered. It may be worth noting that developments in the use of fuel for domestic purposes may alter the composition of flue gases, and consequently their effects, if any, on materials used for boilers.

m. DURABILITY OF PROTECTIVE COATINGS. Where the resistance of a material depends on a protective coating, such coating should be adequately resistant to corrosive influences and to erosion by liquids and solids passing along the pipe.

When external coatings have to be periodically renewed in order to give the required protection, the likelihood of this being actually done at the correct intervals should be considered.

Data are lacking as to the durability of internal coatings in disposal piping under practical conditions, so that, in the absence of such information, there would seem to be some advantages in using materials which are not dependent upon coatings for their durability.

DURABILITY—MECHANICAL STRENGTH

49. All parts of an installation should be adequately strong to withstand pressures due to head of water, stresses in transport, handling, assembly (including fixing) and wear in use. An adequate margin should be allowed for anticipated corrosion during the required period of use.

PRESSURE. The selection of suitable water-supply pipes for given pressures has been simplified by the issue of British Standards. As regards heads of water which can be built up in disposal systems in the event of stoppages, the heads to allow for should relate to actual possibilities in the installation concerned.

TRANSPORT, HANDLING, AND ASSEMBLY. The possibility of damage to materials and components after being manufactured and before reaching a final position in the completed building should be carefully considered, especially in relation to proposals to use pre-assembled units. The cost of properly protecting plumbing materials and units should be allowed for when selecting materials for different purposes.

WEAR IN USE. Pipes made of ductile materials, or of relatively weak brittle materials, are subject to damage by the users of buildings. Where such pipes cannot be arranged to be out of harm's way they need to be protected, and cost comparisons relating to plumbing materials should take account of this.

THE USE OF MATERIALS

50. Materials for plumbing purposes should be capable of withstanding fatigue stresses due to vibration in the building concerned.

51. When temperature stresses are likely to be produced too high to be taken by a particular material, it may be necessary to consider other materials or to design the system in such a way as to permit expansion and contraction to take place.

52. The liability of movement due to settlement of the parts of the structure to which the piping is attached and the subsequent stresses set up in the material should be allowed for in its selection.

Clayware appliances are liable to be fractured in the settlement of buildings. A typical case is that of a closet pan situated on a timber floor in an upper storey of a building. If the floor settles (one cause could be shrinkage of the floor joists) and the pan is rigidly connected, it may in time become fractured. It is desirable to allow for some flexibility—either in the outgo joint or in the piping assembly to which the closet is fixed. In selecting piping materials, therefore, the need for flexibility of the assembled unit or parts thereof should be borne in mind.

Another example is in the laying of underground piping. If, owing to the nature of the ground, settlement has to be anticipated, the piping should be made either strong enough to resist the stresses involved or flexible enough not to become unduly stressed. If brittle, relatively weak materials are used in such cases and rigidly connected together, fracture of the pipes or parting of the joints is likely to occur.

NATURE OF INTERIOR OF PIPES

53. Interior surfaces of pipes should be sufficiently smooth not to give rise to the collection of deposits or to undue restriction of flow. Pipe sizes for given purposes may have to vary according to the material used. Specially smooth and corrosion-resisting materials may give opportunities for using smaller sizes.

It is possible for small projections on the inside of pipes or fittings to lead ultimately to a stoppage. If a few particles of fibre etc. are caught and held they may in turn collect further solids and eventually, under certain conditions, build up a complete blockage.

Data are available on the rate of flow of water through new pipes of various materials and on the reduction in flow which takes place with age in service, due to increased roughness and diminution in bore. Such data should be considered when selecting piping materials for plumbing purposes and when making any necessary allowances for conditions after years in service. Reduction in flow in pipes to such a degree as seriously to affect the efficient working of plumbing systems has often occurred.

When taking advantage of opportunities to reduce the bore of pipes when they are of specially smooth materials, it should be noted that the velocity of flow through the pipes will be increased if the bore is reduced and that high velocity of flow is a cause of noise in plumbing systems. In disposal systems pipe sizing is governed by other factors besides capacity to take flow. For example, one has to consider the advantages of (*a*) making certain soil and waste pipes large enough so that they are not completely filled with water at critical points during the discharge from appliances—this being a precaution against siphonage of traps which may be necessary even with the conventional provision of anti-siphonage pipes—and (*b*) providing a certain amount of passage way in soil pipes for foreign matters which sometimes find their way down closet pans.

54. Methods of jointing pipes to pipes and pipes to cisterns, tanks, appliances and fittings should not give rise to projections or recesses in the pipe lines liable

to lead to stoppages in disposal systems, or noise or undue loss of flow in water-supply systems.

It is usually desirable that when a change of bore occurs in a pipe the change should be gradual, not abrupt. Burrs should be removed from pipe ends before finally making a connection. Joints between pipes which give rise to annular spaces between the pipe ends may possibly give trouble. Exposed screw threads within pipes may give opportunities for material to collect. In spigot and socket (caulked or filled) joints care is required to obviate the protrusion of materials inside the connection. The same applies to welded and soldered joints.

In water-supply systems the general effect of an obstruction or a sudden change in diameter is to produce turbulent flow resulting in a loss of head and sometimes noise.

METHOD OF SUPPORT

55. Pipes made of materials which are liable to flow under stress (creep) need to be supported at short intervals (or continuously). This fact should be borne in mind in selecting materials for given purposes.

The cost of properly supporting pipes in a plumbing installation should be considered in relation to particular types of job. In a small house with a compact plumbing layout the number of supports required for piping, other than connections to appliances and fixings when passing through walls and floors, may be small, so that materials requiring support at short intervals are in such cases in a more favourable position than when used in other installations with, say, long horizontal runs. Costing estimates for pipe runs, supplied and fixed, at a constant figure, irrespective of the type of job, may therefore be misleading in some cases.

56. Clips and brackets connecting pipes to the inner faces of outside walls should have a minimum of heat conductivity, taking account also of any packing material between pipe and clip.

Low-heat conductivity of clips and brackets is necessary as a frost protection measure, but if insulating material is inserted between the clip or bracket and the pipe then the heat conductivity becomes of less importance.

57. Clips and brackets should be of such material and design as to reduce the likelihood of corrosion between the clip or bracket and the piping which it supports.

Paragraph 48 (d) has mentioned the possibility of electrolytic action at pipe clips.

Owing to the fall on pipes, water formed by condensation tends to collect at the junction of a pipe with its clip or bracket.

ECONOMY

GENERAL ECONOMY

58. The cost of plumbing should be regarded as a total of installation and maintenance. Allowance should also be made for the effect of alternative methods of plumbing on the cost of other work in the same building.

The estimation of maintenance costs likely to be incurred in any given plumbing installation, using given materials, is a difficult matter. The essential point, however, is that in seeking low initial costs the importance of estimating maintenance charges as accurately as possible should not be forgotten.

It is clear that plumbing affects all other building trades in some degree, so that any appreciable general changes in plumbing practice, *e.g.* pre-assembly (coupled perhaps with installation of plumbing work at earlier stages in the construction of a building), may have effects on the other trades. It is not sufficient, therefore, to show that a certain method of plumbing costs more or less than another method—reference should also be made to consequent changes in labour or material costs in other directions.

PRE-ASSEMBLY

59. Shop assembly [1] should be used instead of site work wherever it can be shown that it is more efficient to do so.

a. Shop assembly is often done under better conditions for work, supervision and testing, and gives opportunities for the use of special factory methods of rapid and economical construction.

Jointing of pipes on the site is frequently done in confined situations, creating more difficulties in the case of welded, soldered or caulked joints.

Supervision of site work is difficult and sometimes impossible to do satisfactorily.

Test pressures on disposal piping erected on the site must be limited. Bench test methods applied to pre-assembled piping give a better guarantee of long-period, as well as initial, gas-tightness.

Site welding limits the technique which can be employed

b. Pre-assembled units above a certain size and weight may be cumbersome to transport and handle. They may also be liable to damage between shop and final position on the site. Some forms of such damage might be detected and remedied on the site, but it is possible that other forms, *e.g.* springing of joints, might not be attended to, and this could lead in some cases to serious plumbing defects. Well-made metal-to-metal joints (especially if welded or screwed) may be expected to remain intact during transport; but clayware-to-metal (spigot and socket) joints are more vulnerable to impact and vibration stresses.

c. It may be found that for some cases a combination of shop and site fabrication would lead to the most satisfactory and economical construction (See drawings discussed in Part I.) In these cases it may be possible to pre-assemble, for example, parts of the disposal system, parts of the water-supply piping and a hot-water tank cupboard with tank and piping.

Partial pre-assembly has often been used by plumbing contractors. It seems to be successful provided the problems of job organization can be solved, such as finding constant employment for the men on the site. If generally and systematically used it should reduce costs and speed up construction.

Other examples of partial pre-assembly are : Cutting pipes to dead lengths and threading them off the site, and the use of trap and short branch pipe in one piece to save a joint between trap outgo and branch.

d. In pre-assembled units certain problems arise in connection with the working tolerances required in fitting waste and supply piping to appliances. Some difficulties due to variation in positions of outlets of closets, baths, etc., should be removed when the proposed British Standards for these appliances have been implemented. As regards the connection of a pre-assembled disposal piping unit to standard appliances, the following points call for consideration. The position of the bath is more or less fixed in relation to the walls of the bathroom, and thus the bath outlet constitutes a fixed point. The closet pan, however, can be moved laterally to enter the socket of the branch pipe, and the washbasin might be of such a design as to allow a certain amount of lateral movement on its brackets. Sinks are adjustable laterally on their supports. The use of the more ductile or of thin walled piping materials in the pre-assembled units would help to meet the need for tolerances in fitting because slight bending and springing could be done simply on the site.

When pre-assembled units are made up in a material which depends on a coating for its protection, note should be taken of the practicability and cost of coating after all welding, screwing, etc., has been done. Coating of units above a certain size and complexity may be difficult and expensive, and local facilities for doing it may sometimes be lacking.

e. The degree of pre-assembly which contractors may find it desirable to adopt may depend upon :

i. The job in question, flats giving perhaps better opportunities than houses, and compact groupings of appliances better than dispersed ones.

[1] By "shop assembly" is meant work carried out anywhere except in the final position of the plumbing in the building. It would therefore include assembly of piping units etc. in a site workshop, which may in some circumstances be found to be the best place for such work.

ii. Whether pre-assembly methods are being applied to other components of the building concerned as well as to the plumbing.

iii. The facilities available to the plumbing contractor and the size of his contract.

iv. The type of labour available.

v. The materials available.

It is therefore not desirable to recommend any specific degree of pre-assembly for general application, but every opportunity should be taken to seek plumbing economies in this field. Practical trials with the construction, transport, handling and fitting of pre-assembled units should lead the way to the most efficient and economical methods.

ALTERATIONS, REPAIRS AND REPLACEMENTS

60. In the selection of materials and methods of jointing preference should be given, other factors being equal, to those which permit of economical removal or cutting and refitting.

The softer metals are more easily cut. Compression, union, and some capillary joints, etc. are readily detached and remade.

REDUCTION IN NUMBER OF JOINTS

61. In the interests of economy connections should be eliminated when practicable.

Pipes obtainable in long lengths and capable of being easily bent in a satisfactory manner may need fewer joints and thus present opportunities for economy. The number of pipe fixings will be reduced in proportion to the rigidity of the material.

WEIGHTS OF PIPE WORK, ETC.

62. Preference should be given, other factors being equal, to materials with a high strength/weight ratio, in view of their economy in transport and handling.

The weight of material used may influence the economical size and complexity of pre-assembled units.

EXTERNAL DIAMETER OF PIPES

63. Consideration should be given to the fact that, for a given bore, thin-walled piping occupies less space within buildings and also requires less lagging material (where this has to be used).

METHODS OF JOINTING

64. In general, and in so far as is consistent with efficiency, economy should be secured by reducing the amount of material in joints and by simplifying the jointing process as much as possible.

STANDARDIZATION

65. Standardization of certain manufactured components is desirable in the interests of economy.

A good deal of standardization of pipes, pipe junctions, bends, tees, etc., has already been done. (See relevant British Standards.) It would be an advantage if this standardization, and a limitation of manufactured types, could be extended to other fittings. (See suggestions in Part V, paragraph 123.)

USE OF DETACHABLE JOINTS FOR ACCESS

66. It may be economical to use detachable joints at certain points in a disposal system and thereby save the cost of providing special access doors, eyes or screw caps. This factor may influence the selection of the piping material in certain cases.

When waste piping is connected by means of mechanical joints such joints may sometimes serve for access.

PAINTING

67. Exterior surfaces of exposed piping, etc. should be such as to require the minimum cost of painting. Special consideration should be given in this connection to materials not requiring painting.

FUEL ECONOMY

68. Other factors being equal, piping material of low thermal capacity and conductivity is preferable for carrying hot water.

NOISE PREVENTION

69. Piping, appliances, etc. should be so fixed as not to cause undue noise to be transmitted to the structure.

Pipes should be fixed rigidly to supports holding the pipe firmly at frequent intervals, especially if the pipe is of " hard " material, likely to " ring."

When necessary, sound-insulating materials should be placed between appliances, pipes, etc. and the floors, walls, etc. with which they are in contact. For example, pads may be necessary under closet pans and flushing cisterns and pipes may need to be wrapped when passing through interior walls and suspended concrete floors.

Washers for taps should be of such material and so fitted that the possibility of water hammer, etc., arising in water systems is eliminated as far as possible. It is important to select washers correctly for the purpose required, not only in the original installation but also in replacements. The particular requirements of (*a*) draw taps and stop valves, (*b*) ball taps, and (*c*) hot-water taps should be met in the selection of the material for washers. The fixing and housing of a washer should be such as to prevent it spreading or distorting. Correct sizing is important ; slightly oversized washers can in some cases give rise to noise.

APPEARANCE

70. Where plumbing work is exposed to view, piping materials and methods of jointing should be so chosen as to give a neat appearance.

Appearance is usually improved when the size of visible pipe connections is made small compared with the size of the pipes being connected. Reduction in external diameters which accompanies the use of the thinner-walled pipes is also an advantage from the point of view of appearance.

It seems possible that piping assemblies built up on the bench may be neater in appearance than *in situ* work.

EASE OF CLEANING

71. Where plumbing work is not encased, materials for piping, etc., and methods of jointing should be so chosen as to leave the minimum of uncleanable spaces between piping and structure, and the exterior surfaces of the pipes and fittings should be such as to be easily cleanable.

INSULATING MATERIALS

72. Selection of type and thickness of materials for insulating pipes, cisterns, tanks, etc., against freezing effects, against loss of heat and against warming up of cold water should be made on the basis of the actual conditions obtaining.

73. Insulating materials should be durable, *i.e.* they should perform their required functions for the life of the piping, etc., which they cover.

74. Insulating material should not be such as to form food or nesting material for, or be capable of being damaged by, vermin.

PART III. STANDARD APPLIANCES FOR HOUSING

RECOMMENDATIONS OF A GENERAL CHARACTER FOR THE STANDARDIZATION OF BATHS, WASHBASINS, SINKS, AND WATER-CLOSET SUITES

(The purpose of these notes is to indicate the general lines along which standardization should proceed. For the actual fixing of appropriate dimensions co-operation with the manufacturing side is essential. Committees representing the various interests involved have now been formed by the British Standards Institution for the purpose of preparing the detailed specifications.)

BATHS

HEIGHT

75. The commonly used internal height of 17 in., or thereabouts, over the outlet is acceptable.

76. There should be sufficient clearance under the bath at the outlet to allow for the trap and waste pipe to be above the floor. In the case of one-pipe systems a trap with a 3-in. seal should be allowed for.

(The purpose of the above recommendation is to give ready access to the screw cap at the side of the bottom of the trap and to secure simplicity and economy of labour in fixing trap and wastes. It is true that in certain cases access to the screw cap could be in the ceiling of the room below, but this could only normally apply to a kitchen ceiling of a two-storey house and not to flats, one-storey buildings or ground-floor bathrooms. There might also be some difficulty in the case of concrete floors. Since in standardization the demand is for a bath suiting the general case it seems desirable to proceed on the basis of keeping the whole of the piping mentioned above the floor, in spite of the disadvantages of installing baths which may be as much as 24 in. from floor to rim. It is agreed that a lower height, such as 18 in., is preferable for elderly people, but in view of the need for access and economy in installation it is recommended that the standard bath be provided with feet to give the necessary clearance beneath it.)

LENGTH

77. In the planning of bathrooms for low-cost housing the length of the bathroom is frequently made the same as the overall length of the bath (with a small allowance for building in). If, when this occurs, a choice has to be made between lengths of approximately 5 ft., 5 ft. 6 in. and 6 ft., the 5 ft. 6 in. dimension seems to be the most suitable. To use 5 ft. would restrict space unduly, and it is questionable whether one can justify 6 ft. in low-cost housing. The recommendation is, therefore, that in standardization priority should be given to the 5 ft. 6 in. length overall.

WIDTH

78. Baths should be wide enough inside at the head end for comfort in use. A minimum of 24 in. (inside measurement) at this part (at top level of bath) is suggested.

SHAPE

79. a. For the safety of users baths should be as flat-bottomed as practicable.

b. The fall along the bottom of the bath from head end to outlet should be adequate for drainage.

c. The foot end of bath should be so shaped that:

i. There is adequate space between the end of the bath and the wall for easy connection of supply and waste pipes.

ii. Taps will not drip on to the end wall of the bath, causing staining, but on to the bottom. Also it should be made possible for vessels to be filled easily from the taps. (This is partly a matter of design of taps, which is not dealt with in these notes, but the slope of the end wall of the bath is a contributory factor.)

d. The front side of bath should be so shaped that water-supply pipes can, if desired, be run horizontally behind a panel covering this side of the bath.

e. The slope at the head end of the bath should be such as to make for comfort in use. A slope of about 25° from the vertical is suggested.

f. The rims of the bath at the ends and back should be designed for good joints to walls.

WASTE OUTLET

80. Outlets should be such as to suit a trap of $1\frac{1}{2}$-in. internal diameter and should be located sufficiently far from the wall to allow for easy fixing of overflow, trap, and waste piping.

OVERFLOW OUTLET

81. a. A fully cleanable overflow passage is preferable to the non-cleanable type, but the practical difficulty of providing such an overflow for baths which is at the same time simple and economical is appreciated. It is also realized that even when overflow channels are cleanable the cleaning may not be done. The usual type of bath overflow fitting in which connection is made to a vertical grid on the wall of the bath at the foot end is, therefore, acceptable. The height of this grid should be such that when a heavily built person enters a bath which has been filled to the overflow there is room for displacement without flooding. The actual position for the outlet grid will obviously depend upon the shape of the bath, but presumably it will be about 13 in. above the level of the waste outlet and thus about 4 in. below the rim.

b. The hole for the grid should be such that an overflow waste pipe $1\frac{1}{4}$ in. in internal diameter can be used.

TAP HOLES

82. a. The size of the (squared) holes should be suitable to take $\frac{3}{4}$-in. taps.

b. The spacing of the tap holes should be such that they are far enough apart for ease of manipulation (6-in. minimum suggested) but not so wide apart that a vessel resting on the bottom of the bath cannot be filled from either tap (9-in. maximum suggested). It follows from the above that taps in the corners of the bath are not recommended.

c. As a precaution against back-flow it is recommended that the outlets of the taps should be above the flood rim (*i.e.* top edge) of the bath. It will be noted that this recommendation cannot be followed if the normal globe tap, fixed to the wall of the bath, is used.

d. Taps fixed to walls and not to the bath may in some cases be required. Cover pieces should, therefore, be provided for closing tap holes when necessary.

PANEL

83. a. It is recommended that priority be given to the panelled bath. The advantages of the panelling are:

i. Appearance is better.

ii. Less floor covering (*e.g.* lino) is required.

iii. Cutting of lino round feet of bath is avoided.

iv. "Dead space" under a bath is liable to collect dirt because it is difficult to clean, and it may also be used as a depository for cloths, brushes, etc. which is undesirable from the point of view of general cleanliness.

v. Cleaning of the bathroom is simplified.

vi. It enables water-supply piping to be run parallel to and in front of the bath just behind the panel.

b. The panel should be of a strong and durable material, should be capable of being rigidly and easily fitted and should be easily removable for getting access to pipes. It may be necessary, to avoid burying pipes in external walls (a practice which is undesirable from frost and access standpoints), to bring piping through the panel at the foot end. The panel may be recessed where it meets the floor to provide adequate toe space. It would be sufficient, and perhaps more convenient for fixing, to recess only between the feet of the bath. Panels should be so fixed to the side of the bath (and the flange so formed) that a good grip can be obtained by users in getting in and out of the bath.

c. Allowance should be made for end panels in cases where the head end of the bath is not fitted against a wall.

FEET

84. The feet of the bath should be so placed that they do not obstruct or make it difficult to connect a $1\frac{1}{2}$-in. diameter trap and a 2-in. waste pipe carried out parallel to the foot end of the bath, if this should be desirable in any layout.

SOAP TRAYS

85. It would seem preferable not to make soap trays integral with the bath.

OVERFLOW FITTING

86. It is recommended that, if the standardization of waste fittings is carried out in conjunction with the standardization of baths, provision should be made for a standard connection between the overflow outlet and the waste trap.

WASHBASINS

FORM

87. a. The surface under the edge of the rim at the sides should be wide enough to give play on the brackets, thus allowing sufficient tolerance if it is required to fit the basin to pre-assembled disposal piping.

b. All edges and corners should be rounded for convenience of cleaning.

c. The back of the basin should be so shaped that tap connections can be easily made.

OUTLETS

88. a. Outlets should be bevelled and not rebated. Bevelling makes a much neater joint and ensures the waste fitting being fixed concentric with the opening.

b. The diameter of outlets should be suitable for a fitting of $1\frac{1}{4}$-in. (internal) diameter.

c. The position of the outlet on plan should be such as to allow for easy connection of the waste.

WASTE FITTING

89. The waste fitting should be $1\frac{1}{4}$-in. diameter and the flange bevelled on the underside to suit the countersinking of the outlet.

OVERFLOW

90. An easily cleanable type of overflow is desirable.

TAPS AND TAP HOLES

91. a. Taps should discharge above the flood rim of the basin, consequently the design of the basin should be such as to facilitate this, though this requirement may chiefly concern the design of taps.

b. Tap holes should be squared.

c. Tap holes should be in such a position that the taps will project sufficiently over the basin to enable a vessel to be filled.

SOAP TRAYS

92. Soap trays should be designed so as to enable the soap to dry.

SUPPORTS

93. Brackets should be standardized with the basin.

TOWEL RAILS

94. Towel rails on the sides of the supports often abut too closely on the bath or the closet or the wall for them to be useful. They should be arranged at the front, but not to project beyond the basin. A wider rail can be provided in this position and the towel is more accessible.

HEIGHT FROM FLOOR

95. It may be necessary to specify the height if legs or pedestals are used. 30 in. to 32 in. is recommended.

SINKS

TYPE

96. It is suggested that the following types should be standardized initially:

a. Single sink.

b. Combined sink and wash tub with single outlet.

FORM

97. a. The form of the sink should be rectangular with rounded edges and corners and with the bottom sloping to the outlet.

b. A back shelf is not regarded as essential, but, if it is used, pillar taps should not be incorporated in the shelf.

DEPTH (INSIDE)

98. $8\frac{1}{2}$ in. is suggested for the single sink and for the sink of the combined sink and wash tub.

OUTLET

99. a. The diameter of the outlet of the sink should be suitable for a $1\frac{1}{2}$-in. waste.

b. If the outlet is placed at back centre care should be taken to allow ample room for accommodating the trap which runs waste out through the wall. The centre-end position is considered generally preferable to the back-centre position, provided that the draining board is not fixed over the overflow channel opening. It may be advisable to standardize draining boards and their connection to the sink.

OVERFLOW

100. An easily cleanable weir overflow is recommended.

WATER-CLOSET SUITES

SUITE AS ONE UNIT

101. It is recommended that a closet suite, consisting of flushing cistern, flush pipe and closet pan, be standardized as one unit and that a standard of performance be applied to the suite as a whole.

PERFORMANCE OF SUITE

102. a. The contents of the pan should be cleared with a flush of 2 gallons and tests for performance should be prescribed.

b. It would be advisable also to standardize suites for $2\frac{1}{2}$- and 3-gallon flushes to meet the case where such a flush is allowed.

c. The suite should be designed to operate as quietly as possible.

d. Particular attention should be paid to connections between the various parts —cisterns, flushpipe, and pan—and flushing should not cause a splash over the edge of the pan.

FLUSHING CISTERN

103. a. TYPE. The low-level flushing cistern has the following advantages:

i. It has a better appearance, is simpler to install and to attend to.

ii. It permits the storage cistern to be placed at a lower level than would otherwise be the case, giving in some cases better protection against frost.

b. MATERIALS. The specification should allow for the use of galvanized cast iron, vitreous enamelled cast iron, vitreous enamelled pressed steel, copper, plastics, asbestos cement, wood with sheet-metal lining, clayware, etc.

c. SHAPE. The shape of the cistern can be rectangular in elevation. Tapered sides are not necessary for its function in use.

d. LID. A lid which covers the cistern should be provided.

e. BALL VALVES. Ball valves should be designed to refill the cistern within a certain specified time, not exceeding, say, one minute.

A variety of valves should be standardized to suit various pressure ranges. The range should be stamped on the body of the valve.

Valves should be rigidly fixed to cisterns.

The quality of ball valves should be good to reduce maintenance. A silencing pipe should be fitted and the body of the tap should be perforated with an anti-siphonage hole.

f. FLOAT AND ARM. Clearance should be allowed to prevent sticking. The design should be such as to ensure efficient closure of the ball valve.

g. SIPHON MECHANISM (INCLUDING LEVER AND HANDLE). The mechanism should be non-clanking and of the "siphon," not the "dome and discharge pipe" type. Noise (gurgle) due to the breaking off of the siphonic action at the end of a discharge should be prevented, *e.g.* by boring a small hole just above the bottom of the inlet arm of the siphon.

There should be a minimum of working parts.

h. OVERFLOW. A proper overflow should be provided.

The position of the overflow hole in the cistern should be such that the overflow pipe will take away the full discharge under any pressure likely to arise without flooding the body of the valve.

j. SUPPORTING BRACKETS. These should be included in the specification and be of the cantilever type or suitable for fixing on the wall face, as may be required.

STANDARD APPLIANCES

FLUSH PIPE

104. a. MATERIAL. The flush pipe should be of non-corrodible material.

b. CONNECTION TO PAN. A simple and satisfactory method of connecting the flush pipe to the flushing arm is by means of a lead cone and red-lead packing, but there are other methods which are almost as satisfactory.

CLOSET PAN

105. a. OUTLET. The following types of outlet should be included:

i. Straight P-trap.

ii. S-trap.

iii. 45° turned P-trap (P-traps turned more than 45° from the straight position are not recommended for the proposed specification).

b. SHAPE. To minimize fouling the following suggestions are made:

i. Pans should be so formed that a vertical line from the back of the inner edge of the rim falls within the water surface.

ii. The water surface itself should be about 7 in. long (back to front on centre line).

In general, the shape should be such that adequate flushing occurs. (See paragraphs 101 and 102.)

c. HEIGHT. The maximum height should be 15 in. from base to top of rim, but a lesser height, down to $13\frac{1}{2}$ in., is desirable.

d. TRAP SEAL. Depth of seal should be at least $1\frac{3}{4}$ in.

e. OUTLET:

i. *Height.* 7 in. to centre of outlet for P-trap is suggested.

ii. *Inclination to Horizontal (P-trap).* This should be such as to suit standard cast-iron, also asbestos cement, branches.

iii. *Diameter (Internal).* It is suggested that $3\frac{1}{2}$ in. be used for washdown closets and 3 in. for the siphonic type.

iv. *Diameter (External).* This should be included in the specification as it affects the size of socket to be used on the closet branch; it will, of course, vary with the thickness of the material used.

v. *Form.* The spigot should be corrugated and unglazed for security of jointing.

vi. *Anti-siphonage Pipe Connection.* This should not be on the pan but on the branch pipe or connector.

f. BOLTING DOWN. The number and size of holes for bolts, also their positions, should be included in the specification.

g. SUPPORT. If pads are to be inserted between the base of the pan and the floor for sound insulation these pads should be covered in the specification. They should be non-absorbent.

SEAT

106. a. MATERIAL. This should be non-absorbent.

b. FORM. The seat should be flat on the underside.

c. HINGES. The spacing of hinges should be standardized to fit standard lug spacing on the pan. Hinges should be of non-corrodible metal.

d. BUFFERS. The number of buffers required, their type and the method of fixing should be specified. Screws to buffers should be of non-corrodible metal.

e. COVER. When the closet is placed in the bathroom, it is recommended that a seat cover should be provided; consequently the specification should include a seat cover to meet this case. If the closet is in its own compartment, a seat cover is not considered necessary.

NOTE ON FLUSHING VALVES

107. In the section of our report which deals with flushing cisterns it seems appropriate to mention flushing valves. It has been suggested to us that we should recommend the replacement of cisterns by valves for post-war plumbing because of the advantages of the latter (particularly appearance) and in view of their wide use in America and Europe. After careful consideration we find that we cannot recommend a change over from normal British practice in this respect at the present time, because of the excessive consumption of water which defective valves may entail and because it does not seem to us that a flushing valve proof against waste of water has yet been developed in, or introduced into, this country. Our conclusion has been influenced by the following observations:

a. The construction of flushing valves, of the types known to us, often includes narrow passages liable to become blocked by small particles carried in suspension in the water supply or arising from corrosion or lime deposits. When these passages become blocked the result may be to permit a continuous flow of water.

b. When valve seatings in the mechanism become imperfect through corrosion or wear the same defect may develop.

c. When flushing valves get out of adjustment (as they seem to do at short intervals—sometimes less than six months) they may discharge quantities of water considerably in excess of the designed flush, and readjustment to the correct discharge may require dismantling of the valve.

d. It may be noted that maintenance of flushing valves in low-cost housing would probably be difficult. When comparing valves with cisterns on the score of cost, it should be noted that flushing valves normally require larger supply pipes than flushing cisterns, and it is most undesirable that they should be supplied directly from service pipes on account of the risk of contamination.

e. The problem of noise set up by certain types of flushing valve needs to be solved before the general use of the valves could be recommended.

f. The above observations concern flushing valves which are intended to deliver automatically a definite quantity of water when the lever is pressed. Types of mechanism which discharge water as long as pressure is applied are obviously liable to excessive use of water.

PART IV. NOTE ON BUILDING DRAINAGE

GENERAL

108. The study of the underground drainage forming part of normal building works is one of the subjects to which we have been able to give only partial treatment. (See p. 1, last paragraph.) It is clear that this particular problem merits more detailed consideration and that, moreover, some of the proposals we have made for above-ground pipes need to be taken in conjunction with alterations to the drains, *e.g.* the adoption of the combined soil and waste pipe system with omission of gully traps. However, we have arrived at certain general conclusions which are presented here.

BUILDING DRAINAGE

109. Too little attention has been paid in the past to building drainage, especially that for low-cost houses, with the result that money has been spent on work which is not only unnecessary but is frequently difficult to maintain in good order. Good materials, skilled workmanship, and simplicity of design are the essentials, but the importance of these requirements is not always realized, and consequently drains are frequently laid by men with insufficient skill in this particular kind of work, and supervised by others who have not studied the principles of good drainage. The result is that the most hygienic and economical methods are frequently not used.

All pipes, bricks, and other materials should be as specified by the appropriate British Standard, or should otherwise be of first-class quality.

PIPES

110. In the past there was a tendency to use unnecessarily large pipes with the wrong idea that these were less liable to become choked, but it should be emphasized there is no necessity to use a pipe larger than 4 in. internal diameter for the foul drainage of any ordinary house.

111. There are many stoneware and fireclay pipes on the market which are of poor quality. Rough surfaces, excrescences, and bad joints are frequent causes of stoppages.

JOINTING AND LAYING

112. Jointing, gradient, and alignment are not simple matters, particularly in water-logged trenches or bad ground, and the laying of pipes should only be executed by properly trained operatives. Much damage, too, is often caused in back filling the trenches, and as such damage generally occurs in deep drains it is not easy to detect or remedy when the trench is filled in.

Not infrequently pipes have been laid without a concrete bed or flaunching and, although this may be justifiable for strictly temporary huts in camps, etc., and where the ground consists of rock or stiff clay, the practice of omitting the concrete bed for even low-cost housing is to be discouraged.

Laying of stoneware drains by "self-centring" methods, to save time and secure better joints, should be considered.

VENTILATION

113. Thorough ventilation of the system is important to prevent back pressure on the traps of the appliances and also air locking. The mica-flap air inlet is obviously unsatisfactory, and there is no reason why the inlet should not be at or near the ground level with a simple bar grating. A dirt tray may be added in some situations.

BENDS AND TRAPS

114. The setting of bends and traps is an important matter, and it is generally agreed that the joint between the iron soil pipe and stoneware upturn bend is the weakest spot of any sanitary system.

MANHOLES

115. The commonest defects found in manholes are poor brickwork badly rendered, branch drains brought in at improper angles, bad benching, and light covers easily broken or which fit imperfectly.

116. Properly constructed manholes are an expensive item and are only necessary at main junctions, not at easy bends and 45° Y junctions.

117. It is in buildings of the lowest cost, where the drains are liable to be misused and stoppages occur, that there is the greatest temptation to provide inferior manholes and covers. Stoppages can often be removed by extending the head of the disconnecting trap to the surface and "plunging," or by rodding through

an access on the down pipe or a specially provided rodding eye. Since badly formed manholes are themselves a common source of obstruction to the natural flow, it is a matter for serious consideration whether drains would not function more satisfactorily without manholes, and also whether this course would not result in a vast saving to the community in general, even if on very rare occasions the ground had to be opened up. Buried access covers on the drains are not to be recommended, as they can seldom be found when needed and the covers are liable to be improperly fixed or broken.

TESTING

118. The testing of all drains by a competent person is a deterrent to scamped workmanship which may otherwise be rapidly covered up and escape unnoticed.

PART V. RECOMMENDATIONS FOR FURTHER INVESTIGATION AND RESEARCH

119. SOIL AND WASTE PIPE SYSTEMS. We have thought it advisable to study possibilities of greater economy in respect of waste and soil disposal systems for low-cost houses. Appendix II summarizes the results of some of our practical trials on one-pipe systems for such buildings, but it has not been possible in the time available and with the facilities at our disposal under war-time conditions to do more than carry out preliminary experiments of this nature. It would seem advisable that a systematic investigation of this subject be put in hand, because we feel that in many cases a rationally designed and constructed one-pipe system, even for small housing, may prove to be more economical, and sometimes more efficient in operation, than a two-pipe system. Further research would establish more exactly the conditions under which trap ventilation (by special anti-siphonage pipes) can safely be omitted from simple one-pipe systems. Possibilities in this direction may have an important bearing on costs.

Further investigation, including experimental work, seems also desirable in connection with one-pipe systems of a more complex character, such as for flats and multi-storey buildings generally. American investigators have carried out extensive experiments on this subject. (See Bibliography, items 66, 80, and 81.) This work merits more careful study than we have been able to give to it, and experiments on the same lines could profitably be done here to secure data for the more scientific design of disposal systems for British practice.

Similar work for obtaining or correlating data for the economical and efficient design of water-supply systems might be undertaken.

120. DURABILITY OF MATERIALS. A good deal of the data has been obtained by various investigators on the behaviour of plumbing materials under certain conditions of exposure, but the corrosive and other influences to which plumbing pipes, etc. are subjected in practice are very complex. More research is needed to give reliable data for the selection and use of materials (including methods of jointing), so that piping may be installed with more certainty of its durability for the periods and conditions required than is the case at present. Such research would be particularly useful in relation to certain materials, new to plumbing, which are now claiming attention on the score of economy but about which practical experience as to their behaviour for plumbing purposes is lacking or limited. There is a natural reluctance to use a comparatively untried material for plumbing purposes owing to the serious consequences which may result if the material becomes defective. Research may help in introducing the newer materials into plumbing where they are suitable for such use.

FURTHER INVESTIGATION AND RESEARCH

121. FIELD OBSERVATIONS. We have felt the need for reliable statistics on the behaviour of plumbing systems over long periods of service, *e.g.* the incidence of stoppages, the need for manholes, effects of settlement of buildings, durability of materials under various conditions, etc. It seems likely that some differences in the opinions of experts on what is desirable in plumbing would be resolved and practice made more uniform throughout the country if statistical data on performance were available in a suitable form. Field observations would be a guide to rational design, because, although suitable precautions must be taken for conditions likely to arise, it is not reasonable to make costly provision in all plumbing installations for contingencies which only arise in a very small proportion of cases. This applies, for example, to the provision of access doors, rodding eyes, and manholes. Some authorities favour a more limited use of these than others, on the basis that overall economy is better served by cutting and repairing pipes, etc. in isolated cases of stoppage than by providing expensive means of access in all cases.

Reliable statistics obtained in the field would not only be a useful guide to rational practice in such matters, but also be invaluable in connection with further research into the economical and efficient design of plumbing systems and the durability of plumbing materials.

122. NOISE. We recommend that an experimental investigation into plumbing noises be put in hand.

123. STANDARDIZATION. The work already completed, or in hand, on the standardization of plumbing appliances and fittings is referred to in other parts of this report. It is suggested that standardization be extended to cover other units such as hot-water boilers, precast manholes, certain piping assemblies, cast-iron rainwater gutters and outlets, gullies, etc., and smaller fittings such as brackets, wire balloons, domical gratings, sleeves, thimbles, etc.

Standardization of plumbing equipment should be kept continuously under review to take advantage of any improvements in design and manufacture which may be developed from time to time.

124. PLUMBING SUBJECTS NOT COVERED IN THIS REPORT. For reasons given elsewhere in this report (see p. 1, last paragraph) we have not studied all the branches of plumbing to the same extent. It might be useful at some stage for an inquiry to be conducted into possibilities for greater economy and efficiency in relation to rainwater disposal from roofs, the special plumbing of non-domestic buildings, and other matters to which we have been unable to give much attention.

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GEORGE H. HARRIS
R. G. HETHERINGTON
J. W. LAING
A. LONGWORTH
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JOHN H. MARKHAM
W. M. LLOYD ROBERTS
A. SCOTT
R. S. SIDLE
CHARLES F. WHITE
F. L. BARROW, *Secretary*

APPENDIX I

COMMONLY OCCURRING DEFECTS IN PLUMBING PRACTICE

In the course of our studies we have noted a number of commonly occurring defects in plumbing practice which have been instructive to us in preparing recommendations for improvements. It was thought that it might be of interest to record a few examples of these defects in an appendix. They are listed below under appropriate headings.

FROST EFFECTS

1. Laying service pipes too near to ground level at the point of entering a building, and also exposing them to cold draughts under ground floors.

2. Running service and distributing pipes within external walls or against them in cold parts of the building.

3. Installing piping and storage cisterns in roof spaces too near to the eaves or the roof surface, or without lagging or covering, or without other protection by way of roof boarding, felting and beam filling.

4. Laying water piping in such a way that it cannot be emptied completely, including insufficient support to horizontal runs of lead piping so that sags develop. Also, in this connection, the omission of necessary drain cocks or drain plugs.

5. Omission of a stop valve for handy use by the occupiers of individual dwellings. Omission of stop valves on distributing pipes from cold-water storage cisterns.

CONDITIONS ENCOURAGING COLLECTION OF DIRT AND HARBOURING OF VERMIN

6. Avoidable dead spaces behind pipes and in the fitting of appliances.

7. Holes for pipes not sleeved.

INSANITARY CONDITIONS

The following are the insanitary conditions most frequently complained of:

8. Inefficient flushing of closets.

9. Accumulation of waste on gully gratings.

DEFECTIVE WATER SUPPLY

10. Uncovered storage cisterns.

11. Inadequate supply at cold taps, for which a contributory cause is piping of too small a bore or piping reduced in bore by corrosion and encrustation.

12. Inadequate supply at hot taps for above reasons and on account of incorrect layout of the system.

CORROSION AND WEAR

13. Corrosion of galvanized hot-water tanks. (This often occurs because the choice of materials to meet the given conditions has been incorrectly made in the first place.)

14. Disappearance of wire balloons.

15. Fixing of external pipes so close to walls that they cannot be easily painted.

FRACTURE OF CLOSET PANS IN SERVICE

16. Fracture of closet pans due to outgo connection or branch connection being too rigid.

NOISE

17. Excessive velocity of water flow in pipes due to the use of piping of small bore in conjunction with high pressure. Sharp changes of direction in pipes, sudden changes of diameter and burrs on interior ends of pipes at connections.

18. Incorrect selection of ball valves in relation to pressure.

19. Badly designed or maintained draw-off taps or ball-valves.

20. Use of washers of incorrect material and incorrect size. Also washers incorrectly housed.

21. Flushing cisterns operating noisily on account of inferior design and finish.

DIFFICULTY OF ACCESS

22. Piping so fixed that repairs and replacements are difficult and expensive to make.

STOPPAGES

23. Layouts encouraging the building up of solid material in pipes.

INFERIOR MATERIALS

24. Use of tap washers of inferior quality and unsuitable material which rapidly wear.

25. Early deterioration of closet seat hinges and buffers.

26. Screw caps under traps of washbasins and sinks which cease to be watertight after a few removals.

27. Early deterioration of glazed finish on appliances.

SIPHONAGE OF TRAPS

28. Self-siphonage of traps of sanitary appliances.

AIRLOCK IN PIPES

29. Systems which give airlock trouble in refilling, commonly arising with piping so arranged that it cannot be completely emptied.

In relation to "defects" it seems appropriate to refer in this appendix to the following:

MULTIPLICITY OF TYPES OF THE SAME KIND OF EQUIPMENT

30. While making full allowance for different local conditions we have noted a degree of variety in different types of flushing cisterns, taps, ball valves, compression joints, sanitary ware, lead pipe weights, rainwater goods, etc., which seems unnecessary.

Variety arises to some extent from a desire to cater for individual tastes and from the natural effects of competition between manufacturers handling new designs. Up to a point this operates beneficially in bringing about improvements. On the other hand, the cost of plumbing to the consumer must be unnecessarily high with such variety, because it means that:

a. Costs of manufacture and marketing are likely to be higher when many different types have to be handled.

b. Replacements may have to come from one source only, thus involving delay in delivery and additional transport.

c. Additional time has to be spent by architects and in the order departments of plumbing contractors so as to provide correctly for various local requirements.

APPENDIX II

TESTS FOR SIPHONAGE OF TRAPS CARRIED OUT ON SIMPLE ONE-PIPE INSTALLATIONS

The one-pipe system of plumbing has been in use in this country in a number of multi-storey buildings erected during the past ten years. At an early stage in our inquiry the question arose as to whether any advantages would accrue from the extension of the system to low-cost housing of one and two storeys. The chief reason why we considered this matter was that, at first sight, a one-pipe system, in which soil and waste branches discharged into a common stack, seemed to be more amenable to fabrication in units off the site than a two-pipe system. We thought that, if it were found at a later stage that pre-assembly of one-pipe plumbing units for housing was practicable and desirable under post-war conditions, it would be useful to have data available for the economical and satisfactory design of such systems. We realized that a one-pipe system for a small house might be uneconomical if constructed with a special anti-siphonage vent connection to each trap. Certain investigations in America, and accepted practice in that country and elsewhere, suggested that in some simple one-pipe systems for a small house (particularly with the appliances reasonably well grouped together) most, if not all, of the special venting pipes could be omitted without risk of siphonage of the trap seals. We felt it necessary, however, to confirm this by doing such practical trials, to full scale, as war-time facilities permitted. Facilities afforded by the Ministry of Works, Mr. H. J. Manzoni and Mr. D. E. E. Gibson in London, Birmingham and Coventry respectively, enabled these trials to be made. The results we obtained are given in summarized form on Plate I. More details of the installations than are shown on this chart have been recorded, which can be made available if required.

We do not regard these trials as anything but preliminary, as the conditions under which they were carried out precluded a systematic programme of research such as might have been carried through under peace-time conditions. They are included in this report, because of the interest they may have for those concerned with plumbing generally, and because it seems to us that they enable one to draw certain general conclusions, which are as follows:

a. Simple one-pipe systems for one- and two-storey housing can be designed to operate under practical conditions of use without siphonage of traps in spite of the absence of special trap ventilation.

b. The size of stacks and branches has a controlling influence on the liability to siphonage, the use of 4-in. stacks with 2-in. waste branches giving safer conditions than obtain with smaller stacks and branches.

c. When the washbasin branch is run directly to the common stack it is much less liable to siphonage of its trap than when dropped vertically to the bath branch.

It may be possible to draw further conclusions from the test results after further study and repeated experiments with such modifications of layout as seem desirable.

BIBLIOGRAPHY

I. GREAT BRITAIN

1. *Model By-laws :* Series IV, " Buildings " (Ministry of Health, 1939).

2. *Model Specification of Water Pipes and Fittings* (Ministry of Health, 1924).

3. *Rainwater for Domestic Supplies* (Memo. 183W, Ministry of Health, 1934).

4. *War-time Building Supplies Schedule*, 1943 (Ministry of Works).

5. *Emergency Pipe Repairs* (War-time Building Bulletin No. 12, Department of Scientific and Industrial Research, Building Research, 1941).

6. *The Corrosion of Lead in Buildings*, by F. L. BRADY (Building Research Technical Paper No. 8, Department of Scientific and Industrial Research, 1934).

7. *Report of the Departmental Committee appointed to inquire and report with regard to the Use of Intercepting Traps in House Drains*, 1912 (H.M. Stationery Office).

8. *Drainage By-laws*, 1934 (London County Council).

9. *Minimum Specification* (No. I) *for the Installation of Soil, Waste and Ventilating Pipes and for the "Combined System" of Soil, Waste and Ventilating Pipes* (Institute of Plumbers, January 1938).

10. *Minimum Specification* (No. II) *for the Fixing of Cold-water Services* (Institute of Plumbers, 1933).

11. *Minimum Specification* (No. III) *for Drainage Work in Connection with Buildings* (Institute of Plumbers, June 1935).

12. *Minimum Specification* (No. IV) *for the Installation of Cold- and Hot-water Services* (Institute of Plumbers, 1943). (Superseding Specification No. II.)

13. *The Future of Plumbing* (The National Registration of Plumbers, 1942).

14. *Model By-laws, including Specification of Standard Water Pipes and Fittings* (British Waterworks Association, 1933).

15. *By-laws*, 1934 (Metropolitan Water Board).

BRITISH STANDARDS	*B.S. No.*	*Year*
16. *Code of Practice for the Provision of Engineering and Utility Services in Buildings*	1043	1942
17. *Identification of Pipes, Conduits, Ducts and Cables in Buildings*	617	1942
18. *Drawn Lead Traps* (Revision in abeyance for duration of war)	504	1933
19. *Lead Pipes for other than Chemical Purposes*	602	1939
20. *Lead Pipes* (B.N.F. Ternary Alloy (No. 2))	603	1941
21. *Lead Alloy Pipes* (War-Emergency Issue)	1085	1943
22. *Cast-iron Pipes (vertically cast) for Water, Gas and Sewage and Special Castings for use therewith*	78	1938
23. *Cast-iron Spigot and Socket Drain Pipes*	437	1933
24. *Schedule of Cast-iron Drain Fittings, Spigot and Socket Type for use with Drain Pipes to B.S. 437 (1933)*	1130	1943
25. *Cast-iron Spigot and Socket Soil, Waste, Ventilating and heavy Rainwater Pipes*	416	1935
26. *Cast-iron Spigot and Socket light Rainwater Pipes (cylindrical)*	460	1932
27. *Cast-iron Manhole Covers and Frames (light)*	497	1933
28. *Wrought-iron Tubes and Tubulars, Gas (light), Water (medium), Steam (heavy) qualities*	788	1938
29. *Steel Tubes and Tubulars, Gas (light), Water (medium), Steam (heavy qualities)*	789	1938
30. *Ditto* (War-Emergency Specification)	789A	1940
31. *Steel Spigot and Socket Pipes and Specials for Water, Gas and Sewage*	534	1934
32. *Galvanized Mild Steel Cisterns, Tanks and Cylinders* (War-Emergency Specification)	417	1940
33. *Pressed Steel Galvanized Rainwater Gutters, Pipes and Fittings*	1091	1942

	B.S. No.	Year
34. *Copper Tubes and their Screw Threads (primarily for domestic and similar work)*	61	1913
35. *Light Gauge Copper Tubes*	659	1936
36. *Copper Cylinders for domestic purposes* (Grades 1, 2 and 3)	699	1936
37. *Copper-alloy Pipe Fittings, Screwed, for low and medium pressure B.S. Copper Tubes*	99	1922
38. *Soft Solders* (War-Emergency Issue) (Memo. PD 48 and PD 76)	219	1942
39. *Dimensions of Drain Fittings, Salt-glazed Ware and Salt-glazed Glass (vitreous) Enamelled Fireclay* (Amendment slip PD 54)	539	1937
40. *Salt-glazed Ware Pipes, including Taper Pipes, Bends and Junctions*	65	1937
41. *Salt-glazed Glass (vitreous) Enamelled Fireclay Pipes, including Taper Pipes, Bends and Junctions*	540	1937
42. *Asbestos Cement Spigot and Socket Rainwater Pipes, Gutters and Fittings (Dimensions and Workmanship of)*	569	1934
43. *Asbestos Cement Spigot and Socket Soil, Waste and Ventilating Pipes and Fittings*	582	1943
44. *Asbestos Cement Pressure Pipes*	486	1933
45. *Cement Concrete Cylindrical Pipes and Tubes (not reinforced)*	556	1934
46. *Pipe Threads*, Part I, " Basic Sizes and Tolerances "	21	1938
47. *Malleable Cast-iron and Cast Copper Alloy Pipe Fittings (screwed B.S.P. Taper Thread) for Steam, Water, Gas and Oil*	143	1938
48. *Bib, Pillar, Globe and Stop Taps from ¼-in. to 2-in. size and Ball Taps* (War-Emergency Specification)	1010	1942
49. *Flushing Cisterns for Water-closets* (War-Emergency Issue)	1125	1943

50. *Specification of Plumbing and Glazing* (Manchester Architects' and Builders' Consultative Board, 1936).

51. *Report of the Conference on Damage to Plumbing Work caused by Frost* (Science Standing Committee, *R.I.B.A. Journal*, 1930, Vol. 37, No. 18, 681-2).

52. *The Architects' Journal Library of Planned Information*, Vols. 1-5, 1933–39, Edited by Sir JOHN BURNET, TAIT and LORNE.

53. *The Protection of Pipes* (Technical Publications Bulletin No. 10, Lead Industries Development Council, London).

54. *Copper Pipe-line Services in Buildings* (Copper Development Association, London, 1938).

55. *The Sanitary Inspector's Handbook*, by H. H. CLAY (H. K. Lewis and Co., Ltd., London, 5th edition, 1942).

56. *Modern Sanitary Engineering*, by G. E. MITCHELL (George Newnes Ltd., London, 1941).

57. *Model Building By-laws Illustrated*, by G. E. MITCHELL (B. T. Batsford Ltd., London, 1939).

58. *Building Laws, By-laws and Regulations*, by B. PRICE DAVIES (The Building Estimator Publications, Cardiff, 1938).

59. *Sanitary Law and Practice*, by W. ROBERTSON, C. PORTER, J. FENTON (The Sanitary Publishing Co., Ltd., London, 8th edition, 1935).

60. *The Examination of Water and Water Supplies*, by E. V. SUCKLING (J. and A. Churchill, 5th edition, 1943).

61. *The Corrosion of Iron and Steel, being an account of the work of the Corrosion Committee of the Iron and Steel Institute and the British Iron and Steel Federation*, by J. C. HUDSON (Chapman and Hall, 1940).

62. *Practical Acoustics and Planning against Noise*, by H. BAGENAL (Methuen and Co., Ltd., London, 1942).

63. *Sound Transmission in Buildings*, by R. FITZMAURICE and W. ALLEN (H.M. Stationery Office, 1940).

64. *Encyclopaedia of Plumbing, Heating and Sanitary Engineering*, Vols. I-III, S. G. B. STUBBS, Editor (Waverley Book Co., Ltd., London, 1939).

65. *Plumbing and Domestic Engineering*, Vols. I-IV, E. T. SWINSON, Editor (George Newnes Ltd., London, 1935–36).

II. UNITED STATES OF AMERICA

66. *Recommended Minimum Requirements for Plumbing* (Report of Sub-Committee on Plumbing of the Building Committee, Revised, August 1928. Progress revision, May 1931. U.S. Department of Commerce, National Bureau of Standards. Buildings and Housing B.H. 13 and 13A).

67. *Plumbing Manual* (Sub-Committee of Plumbing, Central Housing Committee on Research, Design and Construction. Building Materials and Structures Report B.M.S. 66 (1940), U.S. Department of Commerce, National Bureau of Standards).

68. *Emergency Plumbing Standards for Defense Housing* (Division of Defense Housing Co-ordination, Office of Emergency Management, February 1942).

69. *Back Flow Prevention in Over-rim Water Supplies*, by G. E. GOLDEN and R. B. HUNTER (Building Materials and Structures Report B.M.S. 28 (1939), U.S. Department of Commerce, National Bureau of Standards).

70. *Methods of Estimating Loads in Plumbing Systems*, by R. B. HUNTER (Building Materials and Structures Report B.M.S. 65 (1940), U.S. Department of Commerce, National Bureau of Standards).

71. *Water-distributing Systems for Buildings*, by R. B. HUNTER (Building Materials and Structures Report B.M.S. 79 (1941), U.S. Department of Commerce, National Bureau of Standards).

72. *Strength of Sleeve Joints in Copper Tubing made with various Lead-base Solders*, by A. R. MAUPIN and W. H. SWANGER (Building Materials and Structures Report B.M.S. 83 (1942), U.S. Department of Commerce, National Bureau of Standards).

73. *Plumbing Fixtures : (for) Land Use* (Formed-metal plumbing fixtures). WW-P-542, October 11, 1940 (U.S. Federal Specification).

74. *Plumbing Fixtures : (for) Land Use.* WW-P-541a, March 30, 1940 (U.S. Federal Specification).

75. *Federal Specifications*, Index, revised to July 1st, 1940 (*Federal Standard Stock Catalogue*, Section IV, Part I). Specifications are listed for the following :
    a. *Pipe Nipples of Brass, Steel and Wrought Iron.*
    b. *Cast-Iron Drainage, Waste and Vent Pipes. Seamless Copper Pipes. Wrought Steel and Ferrous Alloy Pipes. Cast-Iron Pipes for Water. Black and Zinc-coated Welded Wrought Iron Pipes.*
    c. *Threaded Pipe Fittings of Brass, Bronze, Cast Iron and Malleable Iron.*
    d. *Seamless Tubing of Copper, Brass, Aluminium and Aluminium Alloys.*
    e. *Unions of Malleable Iron or Steel, Brass or Bronze.*
    f. *Angle, Globe, Gate and Radiator Valves of Brass or Bronze.*
    g. *Asbestos-cement, Clay and Concrete (non-pressure) Pipes.*
    h. *Setting Compound, Gaskets and Packing.*

76. *American Standards Association.* Specifications for :
    a. *Cement Mortar Lining for Cast-Iron Pipe and Fittings* (1939).
    b. *Soldered-joint Fittings* (1941).
    c. *Scheme for the Identification of Piping Systems* (1928).
    d. *Cast-Iron Soil Pipe and Fittings* (1935).

77. *Farm Plumbing*, by G. M. WARREN (Farmers' Bulletin, No. 1426, U.S. Department of Agriculture, 1936).

78. *Plumbing and Public Health* (Public Health Bulletin, No. 256, U.S. Public Health Service, 1940).

79. *Building Code of the City of New York*, effective January 1, 1938 (The Eagle Library, Inc., Brooklyn, N.Y.

80. *Tests on the Hydraulics and Pneumatics of House Plumbing*, by H. E. BABBITT (University of Illinois Bulletin, 1924, Vol 21, No. 47; Engineering Experiment Station Bulletin, No. 143).

81. *Tests on the Hydraulics and Pneumatics of House Plumbing*, by H. E. BABBITT (University of Illinois Bulletin, 1928, Vol. 25, No. 46; Engineering Experiment Station Bulletin, No. 178).

82. *Design, Construction and Equipment*, No. V, "Planning, Building, Sanitation and Equipment of Buildings" (The President's Conference on Home Building and Home Ownership, Washington, D.C., 2nd edition, 1934).

83. *Plumbing Engineering*, by W. S. L. CLEVERDON (Pitman Publishing Corporation, New York and Chicago, 1937).

84. *Plumbing*, by H. E. BABBITT (McGraw-Hill Book Company, Inc., New York and London, 1928).

85. *Piping Handbook*, by J. H. WALKER and S. CROCKER (McGraw-Hill Book Company, Inc., New York and London, 3rd edition, 1939).

III. THE DOMINIONS

86. *Requirements bearing on Health and Sanitation* (National Building Code, Part 5: National Research Council of Canada, Ottawa, June 1940).

87. *A Standard Plumbing By-law* (National Building Code: National Research Council of Canada, Ottawa, June 1940).

88. *Australian Standard Specifications for Plumbing Fixtures*, Part 7 of Commercial Standard No. 10—*Equipment and Supplies for Use in Public Institutions* (Standards Association of Australia, 1938).

89. *Australian Standard Specification for Sanitary Flushing Cisterns*, No. B. 34 (1934) (Standards Association of Australia).

90. *The Auckland City By-laws*, Nos. 1 and 2, 1925 (Corporation of the City of Auckland, New Zealand).

IV. EUROPE

91. *Grundstücksentwässerung und Wasserversorgung* ("Site Drainage and Water Supply"), DIN Taschenbuch 16, January 1931 (Deutscher Normenausschuss. (German Standardization Committee.) Containing DIN 1986, 1987, 1988 covering principles of Plumbing, together with related DINs covering components of the installation system.

92. *Norme per l'esecuzione di installazioni d'acqua potabile* ("Standard Specifications for Domestic Water Installations"), (Schweiz. Verein Gas u. Wasserfach. Monatsbulletin, 1940, Vol. 20, No. 2, pp. 22-9).

93. *Richtig Installieren* ("Correct Installation"), by M. MENGERINGHAUSEN and G. EHLERS (V.D.I.—Verlag G.M.B.H., Berlin, 1933).

94. *Hausinstallation* ("House Installation"), by P. FROMMER, B. G. TEUBNER (Leipzig and Berlin, 1934).

95. *Der Hochbau* ("Building Structures"), EDINGHAUS (Berlin, 1936).

BIBLIOGRAPHY

96. *Kalender für Gesundheits- und Wärmetechnik*, 1938 (" Calendar for Sanitary and Heating Technology "), (R. Oldenbourg, Munich and Berlin, 1938).

97. *Geräuschlose Wasserleitungen* (" Noiseless Water Systems "), by M. MENGERINGHAUSEN (Internationaler Verband für Wohnungswesen, Frankfurt am Main, 1934).

98. *Sanitäre Hausinstallation* (" Sanitary House Installation "), by E. BOSSHARD (Schweizer Baukatalog, 1940, p. 493).

99. *Gesundheits-Ingenieur* (" The Sanitary Engineer "), a German technical journal, published weekly.

100. *Das Gas- und Wasserfach* (" The Gas and Water Engineer "), a German technical journal, published weekly.

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NOTES

DRAWINGS

1. For simplicity the elevations show developed lengths of branches and not their actual elevations.
2. Waste seals are 3" except where otherwise stated.
3. Dimensions shown at W.C. connections give diameter of outgo.
4. Reference:
   W. W.C. set.
   B. Bath.
   L. Washbasin.
   S. Sink.
   V. Vent.

TESTS

5. Each test was carried out 6 times.
6. Figures in tables give losses of seal on trap.

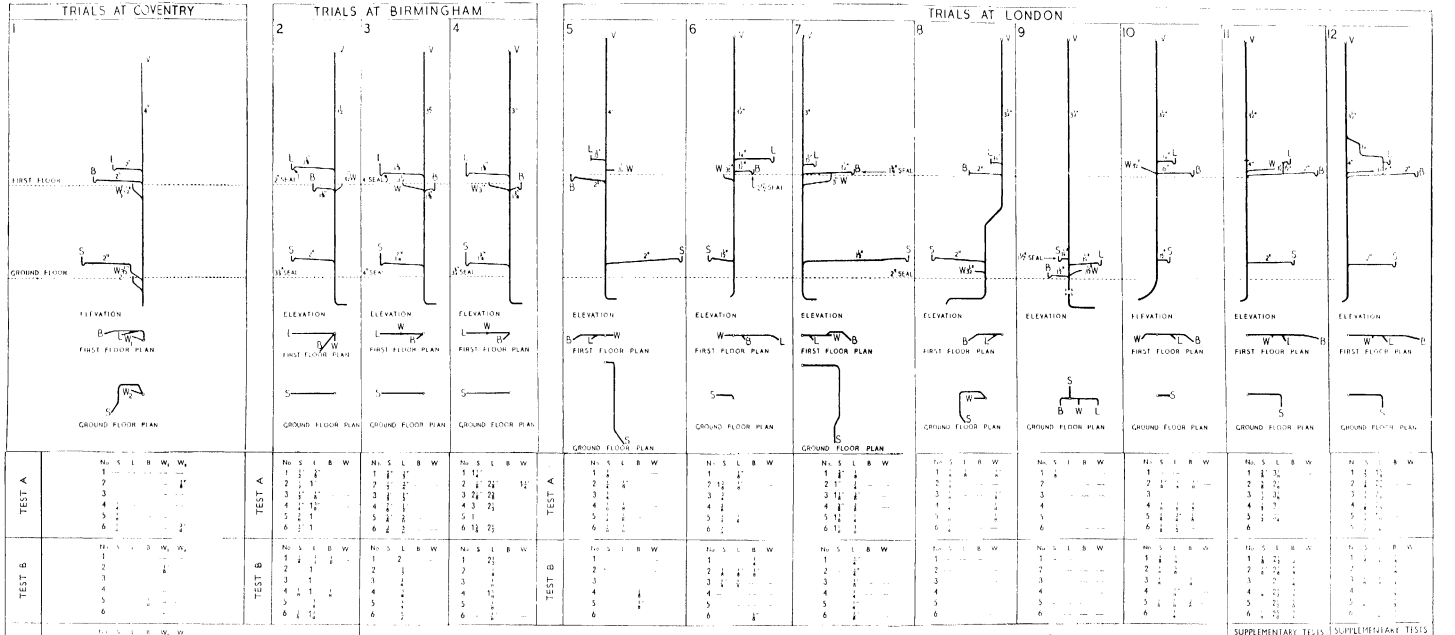
TESTS FOR SIPHONAGE OF TRAPS ON SIMPLE ONE-PIPE INSTALLATIONS

(ABBREVIATED RECORD)

TRIALS AT COVENTRY

TRIALS AT BIRMINGHAM

TRIALS AT LONDON



TEST A

"DRY SINK" TEST

1. Washbasin and bath filled to overflow.
2. 6 pieces of newspaper 8" × 6" placed in each closet pan.
3. Plugs removed from waste outlets and 2 gallons water tipped into each pan.
4. Pans flushed from cistern immediately after discharge from buckets.

	No.	1	2	3	4	5	6	7	8	9	10	11	12
TEST A	S												
	L												
	B												
	W1												
	W2												

TEST B

"DRY BATH" TEST

As Test A, but reading sink for bath

	No.	1	2	3	4	5	6	7	8	9	10	11	12
TEST B	S												
	L												
	B												
	W												

TEST C

DRY GROUND FLOOR CLOSET" TEST

1. Washbasin, bath and sink filled to overflow.
2. 6 pieces of newspaper 8" × 6" placed in upper closet pan.
3. Plugs removed from waste outlets and 2 gallons water tipped into upper closet pan.
4. Pipes pan flushed from cistern immediately after discharge from bucket.

	No.	1	2	3	4	5	6	7	8	9	10	11	12
TEST C	S												
	L												
	B												
	W												

* Large air bubbles passed through seal of ground floor closet.

† A rise of ¼" occurred.

TEST A

No.	S	L	B	W
1	1¼	¼	¼	—
2	1	¼	¼	—
3	¾	¼	¼	—
4	¾	¼	¼	—
5	¾	¼	¼	—
6	¾	¼	¼	—

TEST B

No.	S	L	B	W
1	1	¼	¼	—
2	1	¼	¼	—
3	1	¼	¼	—
4	1	¼	¼	—
5	1	¼	¼	—
6	1	¼	¼	—

TEST A

No.	S	L	B	W
1	1¼	¼	¼	—
2	1¼	¼	¼	—
3	1¼	¼	¼	—
4	1¼	¼	¼	—
5	1¼	¼	¼	—
6	1¼	¼	¼	—

TEST B

No.	S	L	B	W
1	1	¼	¼	—
2	1	¼	¼	—
3	1	¼	¼	—
4	1	¼	¼	—
5	1	¼	¼	—
6	1	¼	¼	—

TEST A

No.	S	L	B	W
1	1¼	¼	¼	—
2	1¼	¼	¼	—
3	1¼	¼	¼	—
4	1¼	¼	¼	—
5	1¼	¼	¼	—
6	1¼	¼	¼	—

TEST B

No.	S	L	B	W
1	1	¼	¼	—
2	1	¼	¼	—
3	1	¼	¼	—
4	1	¼	¼	—
5	1	¼	¼	—
6	1	¼	¼	—

TEST A

No.	S	L	B	W
1	1	¼	¼	—
2	1	¼	¼	—
3	1	¼	¼	—
4	1	¼	¼	—
5	1	¼	¼	—
6	1	¼	¼	—

TEST B

No.	S	L	B	W
1	1	¼	¼	—
2	1	¼	¼	—
3	1	¼	¼	—
4	1	¼	¼	—
5	1	¼	¼	—
6	1	¼	¼	—

TEST A

No.	S	L	B	W
1	1	¼	¼	—
2	1	¼	¼	—
3	1	¼	¼	—
4	1	¼	¼	—
5	1	¼	¼	—
6	1	¼	¼	—

TEST B

No.	S	L	B	W
1	1	¼	¼	—
2	1	¼	¼	—
3	1	¼	¼	—
4	1	¼	¼	—
5	1	¼	¼	—
6	1	¼	¼	—

TEST A

No.	S	L	B	W
1	1	¼	¼	—
2	1	¼	¼	—
3	1	¼	¼	—
4	1	¼	¼	—
5	1	¼	¼	—
6	1	¼	¼	—

TEST B

No.	S	L	B	W
1	1	¼	¼	—
2	1	¼	¼	—
3	1	¼	¼	—
4	1	¼	¼	—
5	1	¼	¼	—
6	1	¼	¼	—

TEST A

No.	S	L	B	W
1	1	¼	¼	—
2	1	¼	¼	—
3	1	¼	¼	—
4	1	¼	¼	—
5	1	¼	¼	—
6	1	¼	¼	—

TEST B

No.	S	L	B	W
1	1	¼	¼	—
2	1	¼	¼	—
3	1	¼	¼	—
4	1	¼	¼	—
5	1	¼	¼	—
6	1	¼	¼	—

TEST A

No.	S	L	B	W
1	1	¼	¼	—
2	1	¼	¼	—
3	1	¼	¼	—
4	1	¼	¼	—
5	1	¼	¼	—
6	1	¼	¼	—

TEST B

No.	S	L	B	W
1	1	¼	¼	—
2	1	¼	¼	—
3	1	¼	¼	—
4	1	¼	¼	—
5	1	¼	¼	—
6	1	¼	¼	—

TEST A

No.	S	L	B	W
1	1	¼	¼	—
2	1	¼	¼	—
3	1	¼	¼	—
4	1	¼	¼	—
5	1	¼	¼	—
6	1	¼	¼	—

TEST B

No.	S	L	B	W
1	1	¼	¼	—
2	1	¼	¼	—
3	1	¼	¼	—
4	1	¼	¼	—
5	1	¼	¼	—
6	1	¼	¼	—

TEST A

No.	S	L	B	W
1	1	¼	¼	—
2	1	¼	¼	—
3	1	¼	¼	—
4	1	¼	¼	—
5	1	¼	¼	—
6	1	¼	¼	—

TEST B

No.	S	L	B	W
1	1	¼	¼	—
2	1	¼	¼	—
3	1	¼	¼	—
4	1	¼	¼	—
5	1	¼	¼	—
6	1	¼	¼	—

TEST A

No.	S	L	B	W
1	1	¼	¼	—
2	1	¼	¼	—
3	1	¼	¼	—
4	1	¼	¼	—
5	1	¼	¼	—
6	1	¼	¼	—

TEST B

No.	S	L	B	W
1	1	¼	¼	—
2	1	¼	¼	—
3	1	¼	¼	—
4	1	¼	¼	—
5	1	¼	¼	—
6	1	¼	¼	—

TEST A

No.	S	L	B	W
1	1	¼	¼	—
2	1	¼	¼	—
3	1	¼	¼	—
4	1	¼	¼	—
5	1	¼	¼	—
6	1	¼	¼	—

TEST B

No.	S	L	B	W
1	1	¼	¼	—
2	1	¼	¼	—
3	1	¼	¼	—
4	1	¼	¼	—
5	1	¼	¼	—
6	1	¼	¼	—

TEST A

No.	S	L	B	W
1	1	¼	¼	—
2	1	¼	¼	—
3	1	¼	¼	—
4	1	¼	¼	—
5	1	¼	¼	—
6	1	¼	¼	—

TEST B

No.	S	L	B	W
1	1	¼	¼	—
2	1	¼	¼	—
3	1	¼	¼	—
4	1	¼	¼	—
5	1	¼	¼	—
6	1	¼	¼	—

SUPPLEMENTARY TESTS

Basin alone discharged.
Bath lost 2", basin lost 2½.
W.C. alone discharged.
(a) Bath lost 1½, basin lost ½.
(b) " " 2" " 1".

SUPPLEMENTARY TESTS

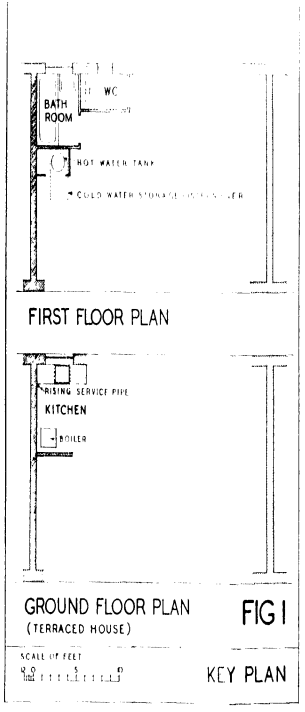
Basin alone discharged.
Basin lost (a) 2", (b) ½".
Bath and Basin discharged:
Losses of seal: Sink ½.
Basin 2½", Bath —, W.C. —.
Bath alone discharged.
No loss on basin.

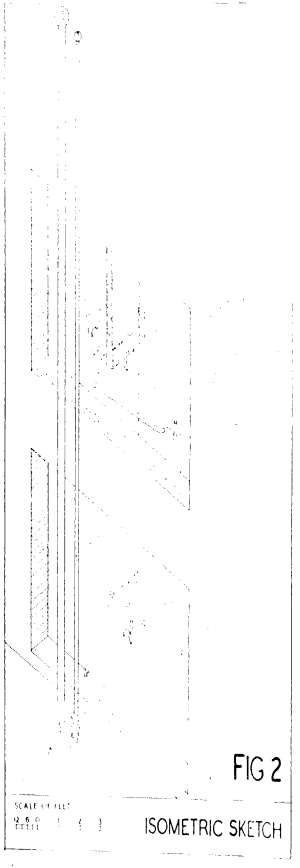
Plate I

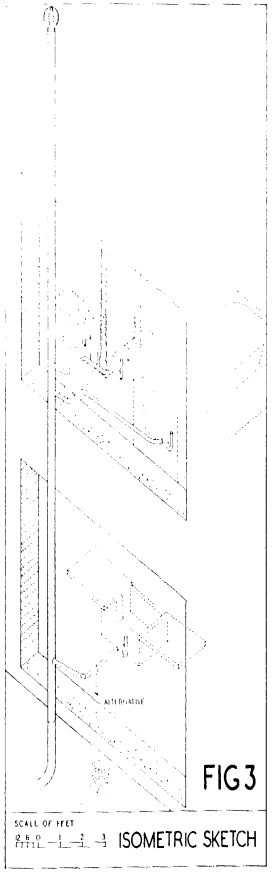
UPSTAIRS BATHROOM AND CLOSET.
COLD WATER STORAGE CISTERN IN ROOF

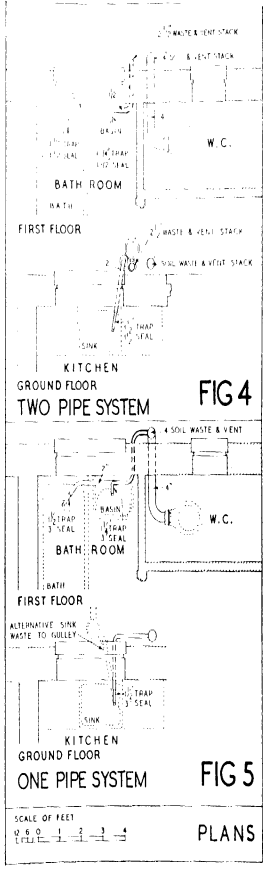
CASE I

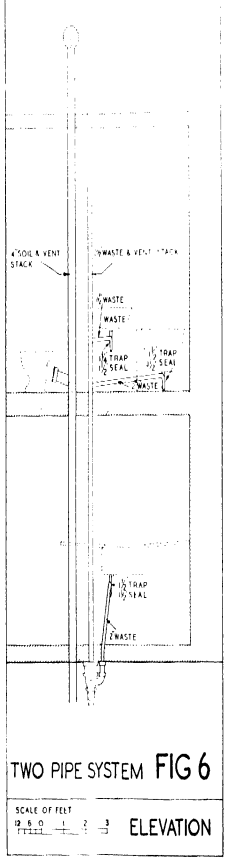
DISPOSAL SYSTEM











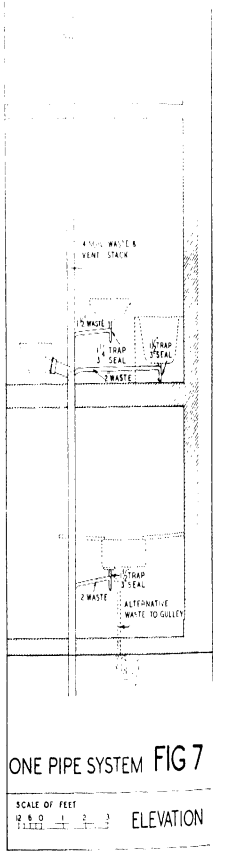


Plate 2

For Supply System, see Facing Plate

ALL PLUMBING WORK ON GROUND FLOOR

CASE 3

WATER SUPPLY SYSTEM.

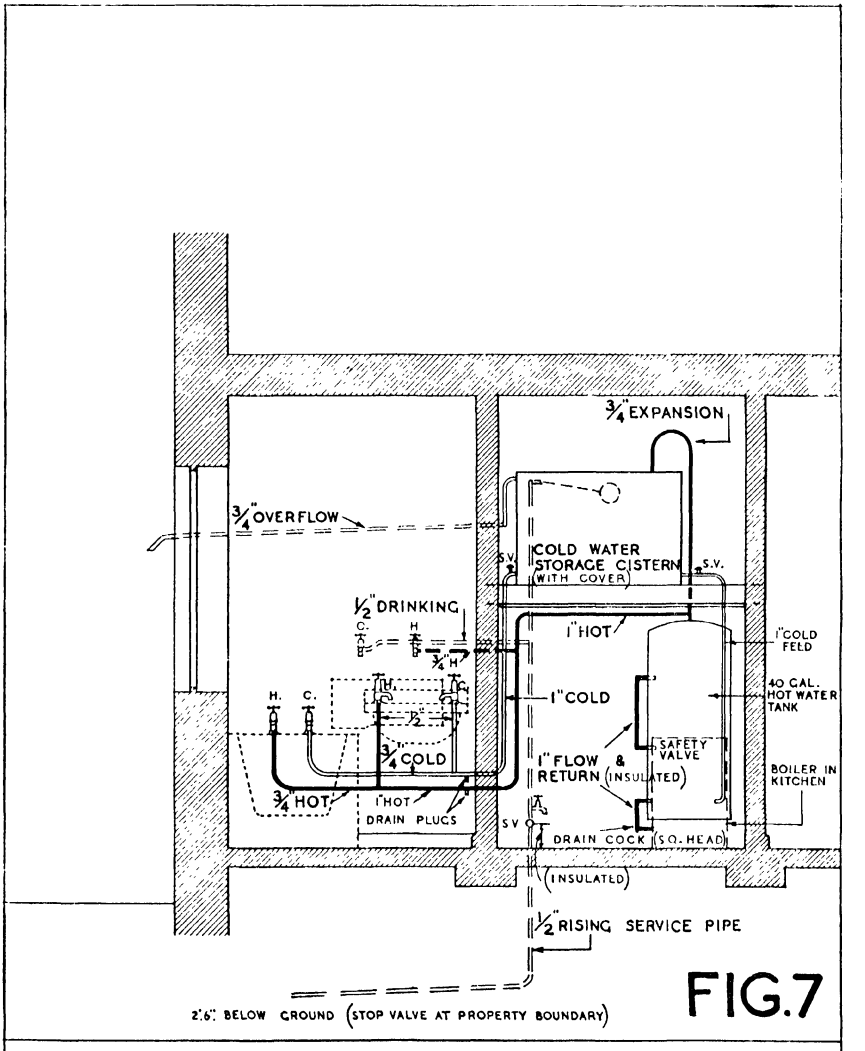


FIG.7

SCALE OF FEET
12 0 1 2 3 4 5

ELEVATION
WATER SUPPLY SYSTEM

Plate 7

GLOSSARY

APPLIANCE. Recipient forming part of a plumbing installation to which water is supplied for human use and from which water passes to the disposal system, such as bath, washbasin, sink or water-closet.

BACK-FLOW. Passage of water by suction or flow from appliance into water-supply system through a tap or valve.

BRANCH PIPE. Soil or waste pipe from trap outlet of appliance to stack.

CISTERN. A container for water the free surface of which is under atmospheric pressure.

DISPOSAL SYSTEM. System of piping conveying discharge from appliances to sewer.

DISTRIBUTOR PIPE. Pipe conveying water from a storage cistern or hot-water apparatus and under pressure from such cistern or apparatus.

DRAIN. Underground conduit forming part of a disposal system.

FITTING. Component of a plumbing installation other than appliance, pipe, cistern, tank, water heater, and similar—in general, a component relatively small in size.

MAIN. Pipe laid by the water undertaking for the purpose of giving a general supply of water as distinct from a supply to individual consumers.

ONE-PIPE SYSTEM. System of piping between appliances and drain in which soil and waste flow down the same stack.

SERVICE PIPE. Pipe directly subject to water pressure from the undertaking's main.

SOIL. Effluent from water-closets, urinals, slop sinks, and the like.

STACK. The principal vertical pipe, or pipes, in a disposal system.

TANK. A permanently closed or sealed container used for the circulation or storage of hot water.

TRAP-VENTING. Employing subsidiary piping for air passage to or from the outgo end of an appliance trap to prevent air pressure or siphonage.

TWO-PIPE SYSTEM. System in which (*a*) separate stacks are used for waste and soil, and (*b*) waste pipes are trapped off from the soil drain and separately vented.

VENT PIPE. Pipe providing flow of air to or from a disposal system.

WASTE. Used water from baths, washbasins, sinks, and the like.

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TERMS OF REFERENCE

i. To review existing scientific information and practice in this country and abroad on plumbing (including the underground drainage forming part of normal building works), with particular reference to the supply of cold and hot water in buildings and the removal of soil, rainwater, and waste therefrom.

ii. To make recommendations for practice in post-war building.

iii. To make such recommendations for further research as may suggest themselves in considering i. and ii.

MINISTRY OF WORKS

POST-WAR BUILDING STUDIES

1. HOUSE CONSTRUCTION
By an Inter-Departmental Committee appointed by the Minister of Health, the Secretary of State for Scotland and the Minister of Works.

2. STANDARD CONSTRUCTION FOR SCHOOLS
By a Committee appointed by the President of the Board of Education.

3. PLASTICS
By a Committee convened by The British Plastics Federation.

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5. THE PAINTING OF BUILDINGS
By a Committee convened by The Paint Research Association.

6. GAS INSTALLATIONS
By a Committee convened by The Institution of Gas Engineers.

7. STEEL STRUCTURES
By a Committee convened by The Institution of Civil Engineers.

8. REINFORCED CONCRETE STRUCTURES
By a Committee convened by The Institution of Structural Engineers.

9. MECHANICAL INSTALLATIONS
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13. NON-FERROUS METALS
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14. SOUND INSULATION AND ACOUSTICS
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15. WALLS, FLOORS AND ROOFS
By a Committee convened by the Royal Institute of British Architects.

16. BUSINESS BUILDINGS
By a Committee convened by the Royal Institute of British Architects.

The following are in course of preparation:

17. FARM BUILDINGS
By a Committee appointed by the Minister of Agriculture and Fisheries.

18. THE ARCHITECTURAL USE OF BUILDING MATERIALS
By a Committee convened by the Royal Institute of British Architects.

19. HEATING AND VENTILATION
By the Heating and Ventilation Committee of the Building Research Board of the Department of Scientific and Industrial Research.

20. FIRE GRADING OF BUILDINGS
By the Fire Grading Committee of the Building Research Board of the Department of Scientific and Industrial Research, and of the Fire Offices' Committee.

21. SCHOOL BUILDINGS FOR SCOTLAND
By a Committee appointed by the Secretary of State for Scotland.

22. FARM BUILDINGS FOR SCOTLAND
By a Committee appointed by the Secretary of State for Scotland.

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POST-WAR BUILDING STUDIES

NO. 6

GAS INSTALLATIONS

BY

A COMMITTEE CONVENED BY
THE INSTITUTION OF GAS ENGINEERS

LONDON: 1944
PUBLISHED FOR THE MINISTRY OF WORKS
BY HIS MAJESTY'S STATIONERY OFFICE
SIXPENCE NET

MINISTRY OF WORKS

POST-WAR BUILDING STUDIES

The series of Reports being published under the title of Post-War Building Studies owes its origin to a desire expressed by professional and other institutions connected with the building and civil engineering industries to assist and support the Ministry of Works in regard to post-war plans. During the latter part of 1941 the then Minister, in order to take advantage of these offers of assistance which he was receiving from all quarters, encouraged the establishment of a series of Committees to investigate and report on the major problems which were likely to affect peace-time building. He also offered, on behalf of the Ministry, to provide the necessary staff and organisation to co-ordinate the various inquiries, in such a way as to avoid duplication of effort and to secure so far as possible uniform direction and policy.

A full list of the Reports which are being issued is given on the back page of the cover.

The Committees were either appointed by a Government Department or convened by a professional institution, a research association or a trade federation, as seemed most appropriate in each case; they were so constituted as to ensure that the Reports contain the considered views of experts and others closely concerned with the subject. The Minister gratefully acknowledges the work of the Committees and the valuable assistance given both by the various convening bodies and by the individual members. The Reports are not official publications in the sense that the Government as such is responsible for or necessarily accepts the views expressed, but their contents are authoritative and cannot but be of great value to all concerned with preparations for building after the war.

INSTITUTION OF GAS ENGINEERS

THE GAS INSTALLATIONS COMMITTEE

To The Right Honourable Lord Portal, d.s.o., m.v.o., Minister of Works

MY LORD, We were convened on 5th May 1942, by the Council of The Institution of Gas Engineers at your invitation. Our study was to be part of a scheme inaugurated by Lord Reith of Stonehaven, when Minister of Works and Building, with the object of securing a comprehensive and co-ordinated review of building technique for the guidance of those who would be responsible for the direction and organisation of building after the war.

We were charged with that part of the general scheme which relates to gas installations. Our terms of reference within this study of building were originally "to review existing information and practice concerning gas installations in buildings, from the point of entry of the gas to property boundary up to the point of its delivery to an appliance, and to make recommendations for practice in post-war buildings." These terms of reference were subsequently amended at a special meeting of the Policy Committee (Installations) of the Ministry of Works held on 27th October 1942, and are as follows:

1. To review existing information and practice concerning installations in buildings for:
   a. The supply of gas for all purposes from the point of entry of the gas to the property boundary to its delivery to an appliance; and
   b. Gas-operated household appliances serving the single family dwelling.
2. To review proposals for improved gas-operated appliances for space heating, cooking, refrigeration, hot-water supply, and clothes washing and drying.
3. To make recommendations for practice in post-war buildings.

The constitution of the Committee is given on page 42.

The Committee has to record with regret the death, on 2nd January 1943, of Mr. Stephen Lacey (London), and the resignation through ill-health, in September 1942, of Mr. Francis Lorne (Ministry of Works), both original members of the Committee. Their places were filled by the appointment of Mr. C. A. Masterman (London) and Mr. J. H. Markham (Ministry of Works) respectively.

The members of the Committee were chosen as being representative of thought and practice in all parts of the country, including Scotland.

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GAS INSTALLATIONS

A REPORT BY A COMMITTEE CONVENED BY
THE INSTITUTION OF GAS ENGINEERS

INTRODUCTION

METHOD OF APPROACH

1. At the first meeting of the Policy Committee (Installations) held on 14th May 1942, the Ministry agreed that the following order of priority should be followed in dealing with installations in buildings: houses, flats, schools, offices and business dwellings, shops and departmental stores, and farm buildings. Since, however, good practice for the supply of gas "from the point of entry of the gas to the property boundary to its delivery to an appliance," to quote the relevant term of reference, is the same irrespective of the size of the building, apart from minor points which have been covered by specific reference, the Committee has not found it necessary in preparing its Report to give prior consideration to any one particular type of building, with the exception of school buildings. In these buildings special problems arise, and the Committee has therefore included in its Report details of a gas installation based on a plan provided by the School Buildings Committee.

2. So far as gas appliances are concerned the Committee has, in accordance with the terms of reference, confined itself to gas appliances for single family dwellings, gas appliances for large buildings being dealt with by the Mechanical Installations Committee, on which The Institution of Gas Engineers is represented.

3. Later, in May 1943, the Ministry of Works requested the Gas Installations Committee to consider "bottled" gas (butane, propane, etc.) installations. A report on butane gas is attached to this Report as Appendix B.

4. In submitting this final Report of its recommendations for the installation of gas service pipes, gas installation pipes, meters and appliances in post-war buildings, the Gas Installations Committee considers that the proper co-ordination at the outset of all concerned in the design and erection of buildings is so important that it desires to reiterate the main points of the Foreword of the British Standard Code of Practice for the Provision of Engineering and Utility Services in Buildings (*B.S.* 1043–1942), as follows:

> "In the initial stages of the design and planning of the building it is of paramount importance that there should be consultations between the architect, the engineers concerned, and all others responsible for the various services.
>
> "It would be of great assistance to all concerned if the architect and/or consulting engineer were to prepare, prior to the commencement of the works, the necessary scale plans, sections and elevations showing (if practicable in different coloured inks) the allotted areas and the agreed disposition and runs of the various pipes, conduits and cables.
>
> "In the interests of both owners and tenants, building specifications and drawings should not be regarded as complete unless such specifications and drawings show that services can be provided at all points where they may reasonably be required.
>
> "The architect and/or consulting engineer should at an early stage in the design and planning of the building confer with the competent public and/or local authority, the local gas, water and electricity undertakings, and the local telephone manager, with a view to ensuring that his proposals will be in accord with all local by-laws and statutory and other requirements.

"In view of the steady expansion of different types of electrical and telecommunication services, and also of gas services, it is essential that careful forethought be exercised in planning to allow for any such development as may occur during the erection of the building or subsequent to its completion. Where there is a probability that a building may be extended, the central heating and ventilating services, etc., may likewise require extension. The Committee has had evidence of the lack of systematic advance planning for services in buildings where, in order to remedy the deficiency, it has been found necessary to adopt methods that are expensive, inconvenient and architecturally undesirable. Where no provision has been made, damage results to walls and floors, finishes and decorations are disfigured, and occupiers put to inconvenience. Walls and floors may have to be cut into and services taken through adjoining rooms and premises, whilst damage may be caused to concealed services in walls. The extent to which such disadvantages can be avoided depends on the adequacy of the systems incorporated in buildings during construction.

"The co-operation of owner, architects, surveyors, consulting engineers, specialists, builders and others responsible for the planning and erection of buildings in arranging for the layout of services with the minimum of inconvenience and trouble to all concerned is, therefore, earnestly solicited."

The Gas Installations Committee, realising the difficulties occasioned by lack of foresight in the planning of gas installations in new buildings, fully endorses the recommendations in the Foreword just quoted.

5. At the request of the Directorate of Post-War Building of the Ministry of Works, the terms of reference have been expanded in accordance with the details enumerated in the main headings of the two Parts dealing with Gas Service Pipes and Internal Installations in post-war buildings.

6. The recommendations for gas installations for post-war buildings have purposely been kept as concise as possible. It is proposed, however, that a booklet shall be prepared by the gas industry in amplification of, and giving explanatory notes on the technical matters referred to in this Report, for the use of the technical personnel in the gas industry.

7. It is understood that the recommendations contained in this Report will form the basis of Codes of Practice, for which purpose The Institution of Gas Engineers has been asked by the Codes of Practice Committee to act as convener body for a Codes of Practice Sub-Committee for gas installations.

8. In the preparation of these recommendations, reference has been made, where relevant, to British Standards already published and to the Code of Practice *B.S.* 1043 1942, "The Provision of Engineering and Utility Services in Buildings."

9. The Committee, in consultation with the Electrical Installations and Plumbing Committees, has agreed that the following nomenclature be standardised for gas, water, and electricity services:

The undertaking's "main" describes the main supply in the street.

The "service pipe" is the pipe between the undertaking's main and the control.

The "control" is the cock or valve controlling the supply from the undertaking to the consumer.

The "internal installation" is the whole of the installation from the control up to and including the appliances.

A fuller glossary of terms used in this Report appears on p. 38.

PART I. GAS SERVICE PIPES

It is desired to draw particular attention to the following:

10. The Committee recommends that the whole of the gas service pipe, that is the pipe between the main and the control, should be installed by the gas undertaking or its authorised contractor.

11. Where a common trench is used for more than one public utility service, the undertakings concerned should consult together with a view to securing agreement with regard to the position and placing of the respective services in the trench.

12. It is recommended that all surface boxes and covers for cocks and valves in gas service pipes should be of a standard design and bear a standard sign indicating their purpose. Identity plates for fixing close to the position of surface boxes should also be of standard design.

13. All ferrous pipes should be adequately protected against external corrosion, having regard to the subsoil in which the pipes are laid.

14. Light-gauge copper has been used to a limited extent in this country for gas service pipes. The Committee has received evidence that where it has been so used it is satisfactory, but it does not consider that sufficient evidence is available at present to justify its general recommendation for use for gas service pipes.

15. The Committee has consulted the British Non-Ferrous Metals Research Association concerning the suitability of lead alloys for gas service pipes, but the information available does not enable the Committee to make any recommendations on this matter.

16. The Committee has reviewed the past and present practice of the gas industry, and finds that few improvements are likely to be made in the immediate future either in materials for or methods of laying gas service pipes. In all but a few cases the whole of the work concerned with service pipes is carried out by the gas undertakings. Long experience combined with recent research has evolved a technique which differs but little throughout the country.

The Committee recommends that the installation of gas service pipes shall be governed by the following suggested Specification:

DEFINITIONS

17. The term "gas service pipe" means the pipe between the gas main and the control (normally at the meter inlet).

The term "pipe fitting" means any coupler, connector, union, elbow, bend or tee-piece used in connection with a pipe.

MATERIALS

18. Gas service pipes should be wrought iron, mild steel, cast iron or such other materials as may be recommended by The Institution of Gas Engineers from time to time, and should comply with the relevant British Standards.

19. The British Standards for wrought-iron, steel, mild steel and cast-iron service pipes and fittings are:

——	Material	Specification Number
Service pipe and service tubulars	Wrought iron (including galvanised pipe)	*B.S.* 788-1938
	Steel	*B.S.* 534-1934
	Mild steel	*B.S.* 789-1938
	Cast iron	*B.S.* 78 1938
Service fittings	Malleable cast iron	*B.S.* 143-1938
	Cast iron	*B.S.* 78-1938
	Wrought iron	No Specification
	Mild steel	No Specification

20. A steel or wrought-iron gas service pipe laid underground should be adequately protected against corrosion, unless the gas undertaking has found by experience that the soil is such as to render protection unnecessary. In very corrosive soils cast-iron pipes may also require protection.

21. All pipe and pipe fittings used as service pipe should previously have been tested at an internal air pressure of not less than 100 lb. per square inch while submerged in water and, if required, a certificate that such a test has been successfully passed should be provided by the manufacturers.

RESPONSIBILITY FOR LAYING

22. When a gas service pipe or any portion of it, situated or to be situated beneath the public way or beneath and within the property boundary, is to be laid, altered, extended or removed, the work should be carried out by the gas undertaking, or if by an approved contractor, in compliance with these recommendations, under the direction of the gas undertaking.

SIZES

23. The gas service pipe to a building should be of a size not less than 1 in. internal diameter, or should be of such larger size as may be determined by the gas undertaking, having regard to the length of service pipe and the probable maximum demand for gas upon the premises.

METHOD OF LAYING

EXCAVATION

24. The trench for the gas service pipe should be excavated to the correct depth (having regard to the fall required) so that the pipe is bedded on solid ground throughout its length. Where a common trench is used there should be consultation between the utility services concerned.

JOINTING

25. Where cast-iron pipes are used the joints should conform with the provisions of *B.S.* 78-1938, and where steel spigot and socket pipes and specials are used the joints should conform with the provisions of *B.S.* 534-1934.

26. Where ferrous pipes, couplers and other pipe fittings with screw threads are used, all threads should conform with *B.S.* 21-1938.

SERVICE PIPES

27. A gas service pipe should be joined to the main by a connector or other suitable coupling for the purpose of facilitating connection or disconnection. Where flexible couplings or joints are used they should be of a type approved by the gas undertaking.

FALL

28. The gas service pipe should be laid with a fall from the meter to the main if the relative levels will allow. Where this is not practicable, a suitable receiver for the reception of condensate should be inserted and fitted with a surface box and cover placed in an approved position outside the building and readily accessible to the gas undertaking. Where a condensate receiver is used a stand pipe for the removal of the condensate should be fitted.

CONTROLS

29. Where a gas service pipe is of 2 in. internal diameter or more, or where it is considered necessary by the gas undertaking, a cock or valve of an approved type should be fixed in the service pipe in a position outside but as near as practicable to the property boundary, and fitted with a surface box and cover.

30. When, by reason of special circumstances, *e.g.* blocks of flats or buildings with a large forecourt, a control cock or valve is fixed in the service pipe within the property boundary, it should be placed in a position close to and readily accessible from the outside of the building.

31. Where a gas service pipe is common to more than one building or tenement, a control cock or valve should be fitted to the service pipe in an accessible position outside the premises, and should be located by a surface box with cover which should indicate clearly that the cock or valve controls the supply to more than one meter.

Every gas service pipe should, in addition, terminate at the meter position with a cock or valve of a type approved by the gas undertaking.

METHOD OF ENTRY

32. In all new buildings provision should be made by the building authority, owner, or agent for a sleeve or sleeves for the entry of public utility services, whether such services are immediately to be connected or not. As far as practicable the gas service pipe should be laid in a straight line and at right angles to the gas undertaking's main. At the point of entry of the gas service pipe, the building authority, owner, or agent should make provision for it to pass through the external wall by means of a sleeve built into the structure, and the space between the pipe and sleeve or structure should be completely filled in with bituminous or other suitable material throughout the thickness of the wall. Where a sleeve is used the space between it and the structure should be filled in solid. The location of the sleeve should be determined in consultation with the gas undertaking. In the event of the service not being installed before the building is completed, the sleeve should be properly capped off at both ends.

DUCTS AND CASINGS

33. Where any part of a gas service pipe is to be laid inside a building, adequate facilities for access thereto should be provided by the building authority, owner, or agent, if necessary by accommodating it in a duct, casing, recess, or channel.

IDENTIFICATION

34. In large buildings that part of a gas service pipe which is inside the building should, where exposed, be finished wholly or in part in the standard basic colour and lettered in accordance with *B.S.* 617–1942, or any revised edition thereof. It is desirable to provide, for ready access on the premises, a line chart indicating the position of the gas service pipe, gas meter and controls, and the layout of the installation pipes. (See paragraph 90.)

PROTECTION

PREVENTION OF EXTERNAL CORROSION

35. For steel pipes complying with *B.S.* 534 1934 the protection should take the form of hessian wrapping or asphalt covering, as laid down in Section 21 of that specification. For steel or wrought-iron pipe complying with *B.S.* 788–1938 the protection should be provided by hessian and bituminous wrapping applied at the tube works, by surrounding the service pipe with a covered wooden trough and filling this with bituminous material, or cement and sand, so as completely to surround the pipe, or by other means approved by the gas undertaking.

Similar protection should be given to any part of the service pipe which is inaccessible or passes through or is in contact with any material liable to cause corrosion.

Service pipes in exposed positions, *e.g.* above ground on the outside of the building or in damp cellars, should be protected by painting with red lead, bituminous paint or by other approved means.

INTERRELATION WITH OTHER SERVICES

36. Where a gas service pipe is laid or fixed in close proximity to other services it should be placed in a position which, by spacing, insulation, or other means, prevents contact with such other services. (See *B.S.* 1043–1942.)

LOCAL DISCONNECTION OF SUPPLY

37. In blocks of flats, offices and buildings of a like character, facilities should be provided on each floor for disconnection of each supply at a position adjacent to its junction with the gas service pipe or installation pipe.

INSPECTION AND TESTING

38. All gas service pipes should be tested by or under the direction of the gas undertaking. The test should be made with air under pressure sufficient to support a column of water 12 in. high, or twice the maximum working pressure, whichever is the greater, for a period of not less than 15 minutes. The test must be made before the protective coating (if any) is applied to the joints of the service pipe.

RECOMMENDATIONS

39. It is recommended that the British Standards Institution be requested to prepare a specification for a standard design for all surface boxes and covers, which should have a standard mark, indicating their purpose. It is also recommended that that Institution be requested to prepare a specification for a standard design for identity plates for affixing on a wall or vertical surface close to the position of a surface box.

PART II. INTERNAL INSTALLATIONS

SECTION I. INSTALLATION PIPES

40. The Committee desires to emphasise the need in the planning of the installation of gas installation pipes for architects, builders and all concerned to consult with the gas undertakings, in order to ascertain whether an adequate supply of gas can be made available for all purposes for which gas may be used (actual or potential) in the building concerned. It is important that every new building should be suitably provided, at the time of its construction, with gas installation pipes and points for the installation of gas appliances. (See paragraph 4.)

41. This recommendation is in accord with the principle of freedom of choice of fuels by the tenant, who is thereby enabled, not only to satisfy individual preferences, but also to make use of technical and economic developments in fuel supply. The normal expenditure of a family on fuel forms so large a part of the total outgoings that the cost of providing the facilities for full benefit to be derived from this expenditure is not disproportionate. In a normal dwelling house the total cost of the fuel used in the house during its life equals or exceeds the cost of the house itself, and the provision of a complete installation of gas pipes and points, in addition to facilities for the use of electricity and solid fuel, appears to be a reasonable standard of equipment in house construction.

42. Alterations to a building after completion are almost always costly to execute and sometimes architecturally unsatisfactory. This applies to the extension of services as well as to alterations to the structure, and it is, therefore, important that there should be close contact between the gas undertaking and the architect in the initial stages of planning buildings. Such contact will enable the gas installation system to be planned with a view to meeting the requirements of a complete gas fuel service, even though it may be uncertain to what extent the occupier will immediately avail himself of such service.[1]

43. All installation pipes and fittings should, on completion and before connection to the meter, be tested for soundness by, or under the direction of, the gas undertaking.

44. The drawings and specifications should not be considered as final unless and until they provide for gas points in all positions where fuel might be used.

DEFINITIONS

45. The term "installation pipe(s)" means all pipes between the control and the points at which the appliances are to be connected.

The term "pipe fitting" means any coupler, connector, union, elbow, bend or tee-piece used in connection with a pipe.

[1] It is not possible to give any exact statement of the increased cost incurred as a result of having to install a supply of gas after the building has been completed instead of at the time of construction. It will certainly be about three times as great, and may be much more than that.

MATERIALS

46. Pipes and pipe fittings should comply with the British Standards and the Specification for solid drawn brass pipe for the gas industry.

47. Admissible materials for installation pipes and pipe fittings are:

i. Wrought-iron or mild steel pipe with wrought-iron, mild steel or malleable cast-iron fittings.
ii. Lead pipe.
iii. Solid drawn copper pipe with copper or copper alloy fittings.
iv. Solid drawn brass pipe [1] with brass fittings.
v. Reinforced rubber pipe with screwed metal ends and flexible metallic pipe with screwed ends for the connection of portable appliances.
vi. Pipes and pipe fittings of other materials which may be recommended by The Institution of Gas Engineers from time to time.

PLASTIC PIPES

48. The Committee has consulted the Plastics Committee concerning the suitability of plastic pipes for gas installations. The Committee is advised that thermoplastic pipes would be unsuitable for use as gas service pipes but that there are other types of plastic pipes which may be suitable for this purpose. The Committee has no evidence as to the use of plastic pipes for gas service pipes or installation pipes in this country, and considers that pipes of such materials should not be used for these purposes until evidence of their suitability is available.

49. The British Standards for gas installation pipes and fittings are:

Material	Specification Number
Wrought-Iron Tubes and Tubulars	*B.S.* 788 1938 Addition March 1938 Addition January 1939
Steel Tubes and Tubulars	*B.S.* 789–1938 Addition March 1938 Addition January 1939
Steel Spigot and Socket Pipes and Specials	*B.S.* 534–1934
Cast-iron Pipes	*B.S.* 78–1938 Addition November 1938
Malleable Cast-iron Fittings	*B.S.* 143–1938
Wrought-Iron Fittings	No Specification
Mild Steel Fittings	No Specification
Light Gauge Copper Tubes	*B.S.* 659–1936 Addition June 1938
Copper Tubulars	No Specification
Copper Fittings	No Specification
Brass Tubing and Fittings	Pending *B.S.* as specified by The Institution of Gas Engineers [2] *B.S.* 602–1939 Addition June 1941 *B.S.* 603–1941
Flexible Metallic Tubing and Connectors	*B.S.* 669–1936
Plug and Socket Gas Connectors	*B.S.* 570–1934

[1] Special brass pipe is required for the gas industry, and the Gas Industry Committee of the British Standards Institution has been asked to prepare a specification for this material.
[2] Regulations Governing the Installation of Gas Service Pipes, Gas Supply Pipes and Gas Appliances, August 1937, Schedule IV.

JOINTING

SCREWED JOINTS

50. Where ferrous pipes, couplers and other pipe fittings with screw threads are used, all threads should conform with *B.S.* 21–1938.

OTHER JOINTS

51. Where other ferrous pipes are used the joints should conform with the provisions of *B.S.* 78–1938 and *B.S.* 534–1934 for cast-iron and steel respectively.

52. Where non-ferrous pipes, couplers and other pipe fittings are used the joints should comply with the British Standards. All pipe fittings should be of a type approved by the gas undertaking.

JOINTING COMPOUNDS

53. Where jointing compounds are used they should be of a non-corrosive nature, composed of materials which will facilitate the disconnection and remaking of sound joints when necessary.

SIZES

54. In order to ensure that an adequate supply of gas shall be available for all gas appliances (actual or potential) in the premises concerned, it is recommended that the planning and installation of the gas installation pipes should be carried out in consultation with the gas undertaking.

55. The sizes of installation pipes should be determined by the maximum rate of consumption of the appliance. (See Table of Discharge in Appendix C.)

56. No pipe of a size less than $\frac{1}{2}$ in. internal diameter or of a greater length than that prescribed in relation to its diameter (see Appendix C) should be embedded in the structure of the solid floors

57. The principal installation pipes should be of such sizes as will provide for any reasonable future demand which, from the character of the building, it is considered likely may be made upon them.

METHODS OF INSTALLATION

HORIZONTAL RUNS

58. In buildings where the floor structure is of fire-resisting construction, in order to prevent subsequent damage to the structure, provision should be made, at the time of construction, for common ducts, channels and chases for public utility services, with convenient access thereto, wherein gas installation pipes may be installed, or for the addition to the structural floor of material of sufficient depth to accommodate the pipes. When changes in pipe level are unavoidable provision should be made for the collection of condensate.

59. In buildings where the floor structure is formed with joists and floor boards, installation pipes should be laid between and parallel with joists and should be provided with proper supports; where this is not possible they may be laid across the joists provided they are in notches or previously prepared grooves on the upper surface of the joists at a distance not greater than 12 in. from the bearing. Notches should be only sufficient in width and depth for the pipes and should not exceed one-sixth of the depth of the joist.

60. Where installation pipes cannot be laid parallel with joists, and the depth of the joist and specified minimum notch do not allow of a pipe of the required size, a number of smaller pipes of equivalent capacity should be used.

61. Where necessary for disconnection, extension or other purposes floor traps secured by screws should be provided at suitable positions.

62. In educational and other public buildings, departmental stores and the like it is desirable to install a horizontal distributing circuit at the lowest convenient level, with controlled vertical branches in appropriate positions, provision being made for such extension as may be advisable.

VERTICAL RUNS

63. Vertical installation pipes should preferably be placed in ducts, with convenient access thereto, specially provided for the purpose. Alternatively, pipes may be placed in chases if the thickness of the wall permits.

POINTS FOR DISCONNECTION AND CLEARING

64. All runs of installation pipe should be provided with sufficient connections of suitable type to permit lengths of pipe to be removed or altered with minimum damage to the structure or surrounding decorations.

65. Provision should be made at the base of each vertical installation pipe for facilities to remove any obstructions that may occur.

REDUCTION OF RESISTANCE

66. The use of sharp radius elbows should be avoided where long sweep elbows or bends can be fitted. Square elbows should not be used. The bore of a supply pipe should not be restricted through either bending or cutting.

DUCTS AND SLEEVES

67. Installation pipes which pass through floors or walls should, wherever possible, be sleeved.

68. All apertures, ducts, channels and sleeves in floors and walls should be provided by the building authority, owner or agent.

69. When installation pipes pass through sleeves or apertures in floors or walls, or are placed in ducts or channels which pass through or under floors or walls, the space between the pipe and sleeve or aperture should be filled in solid, or the duct or channel completely separated at suitable positions, by fire-resisting construction equal to that of the surrounding structure, in accordance with *B.S.* 1043–1942.

70. Every filling or separating barrier subsequently disturbed should be restored.

SUPPORTS AND FIXINGS

71. All hangers, supports and fixings for installation pipes should be of sufficient strength and security, regard being paid to appearance if in exposed positions. Where proprietary articles of these types are used they should comply with the relevant British Standard (in preparation).

72. Supports or fixings should be of such distance apart as to ensure proper support, correct alignment and rigidity; they should be firmly secured to the structure with incombustible material. Arrangements should be made, where necessary, to allow for expansion.

73. Where installation pipes have to be run on the surface of a structure the support should be such as will keep the pipe clear of the surface.

PROTECTION

PREVENTION OF CORROSION

74. Installation pipes which pass through or are in contact with any material likely to cause corrosion should be adequately protected throughout the area of contact. Installation pipes which must pass through floors of a corrosive nature, or would be exposed to or in contact with chemical effluents, should be encased in sleeves of suitable protective material as may be necessary. All ferrous installation pipes in all positions—exposed or concealed—should be painted or otherwise suitably protected.

INTERRELATION WITH OTHER SERVICES

75. Installation pipes should not pass through electrical intake chambers, transformer rooms, lift shafts, refrigerator chambers or be placed in positions contrary to any rules, regulations or statutory by-laws of any public utility company, undertaking or authority, or in any other position prejudicial to the safety of the pipes.

76. Where laid or fixed in close proximity with other services installation pipes should be placed in positions which, by spacing, insulation or other means, prevent contact with such other services. (See *B.S.* 1043-1942.)

AVOIDANCE OF DAMAGE

77. Installation pipes laid underground or in exposed positions should preferably be of a gauge suitable to ensure long life. If light gauge pipe is used it should be adequately protected against mechanical damage in addition to the protection from corrosion defined in paragraph 74 above.

78. Where non-ferrous pipes are laid under floors, in chases or otherwise concealed, they should be protected against puncture and similar damage.

CONTROLS

SERVICE COCK OR VALVE

79. Every internal installation should be controlled by a service cock or valve of an approved type fitted in an accessible position on the service pipe as close as practicable to the inlet connection to the primary meter.[1] (See Gas Service Pipes: "Controls"; also paragraph 108.)

80. Additionally, an approved type of cock or valve may be fitted on the outlet connections from the primary meter; branch installation pipes to sections may be isolated by cocks or valves or other means of control.

81. The position of any concealed sectional cock or valve within a building should be clearly indicated and its classification identified by a permanent notice fixed as near as possible to the cock or valve.

BY-PASS

82. Where, with the sanction of the gas undertaking, it is agreed that a primary meter shall be by-passed provision should be made for connections on both gas service pipes and installation pipes at the time they are installed, and each by-pass should incorporate an approved type of cock or valve to be secured and sealed by the gas undertaking. (See Section 2, "Gas Meters.")

[1] See "Definition," paragraph 94.

INSTALLATION POINTS

83. The gas installation system should be planned so as to provide for points to meet the requirements of a complete gas fuel service. (See paragraph 40.)

84. The position of points should be determined by the location and planned layout of the equipment for convenient coupling to the standard connections of appliances.

85. The minimum size of any installation pipe to an appliance should conform with paragraphs 54 to 57.

86. Until the connection of the gas appliance with the installation pipe each point should be securely capped or plugged and should be covered by a plate marked "Gas Point."

87. The location of a point for a gas fire or for the ignition of a solid fuel fire should be in a floor trap at the side of the fireplace.

i. Where it has been predetermined to use a gas fire, the cock should be fitted in the floor trap and the installation pipe continued under the hearth to terminate at a convenient position at the back of the floor of the fireplace opening so that the gas fire may subsequently be connected without any pipe work being visible.

ii. Where the choice of fuel is left for future decision, either a sleeve may be embedded in the hearth and the floor of the fireplace opening to enable the pipe subsequently to be inserted through it, or the pipe may be left "dead" with its terminal suitably projected.

It is recommended that, in addition, a flush-fitting type of plug-in socket should be left in the skirting board adjacent to the hearth of every fireplace.

88. Where reinforced rubber or flexible metallic pipe with screwed metal ends is used for connecting a portable appliance, a cock should be fixed in the permanent installation pipe at the inlet to the rubber or metallic pipe. No cock should be fitted to an appliance so used, but portable appliances with taps for the control of individual burners should be connected with metal pipes and unions for easy disconnection if required.

INSPECTION, TESTING AND CERTIFICATION

89. All installation pipe systems should, on completion and before connection to the primary meter, be tested for soundness by or under the direction of the gas undertaking. The test should be carried out in the following manner:

The ends of the installation pipe should be capped, with the exception of one which shall be fitted with a tee-piece carrying a cock on one outlet and a pressure gauge on the other. The test shall be made with air under pressure sufficient to support a column of water 12 in. high or twice the maximum working pressure, whichever is the greater, for a period of not less than 15 minutes.

Installation pipes or sections thereof which will be embedded in the structure should, in addition, be tested as they are laid and before they are covered.

IDENTIFICATION

90. Installation pipes in large buildings should be painted in accordance with *B.S.* 617 1942 or any revised edition thereof. It is desirable to provide, for ready access on the premises, a line chart indicating the position of the gas meter and controls and the layout of the installation pipes. (See paragraph 34.)

RECOMMENDATION

91. In examining the British Standard relating to pipes and connections used for the supply of gas between the meter and the appliance, the Committee has found that there is much confusion in nomenclature of the materials used, the words "pipes," "tubes" and "tubulars" apparently being used rather haphazardly. It desires to recommend that all such materials used be described as "pipes" or "pipe fittings," as appropriate.

SECTION 2. GAS METERS

92. In preparing the recommendations for the installation of gas meters, the Committee has had the advantage of considering the recommendations drawn up in the 1st and 2nd Reports of the Meters Committee of The Institution of Gas Engineers, published in November 1935 (Publication No. 120). It has also been in consultation with the Meter Makers' Section of the Society of British Gas Industries.

93. The recommendations follow very closely those published in the 1st and 2nd Reports of the Meters Committee, but in addition the position of the meter, particularly in small houses or dwellings, has received special attention.

DEFINITION

94. The "primary meter" is a meter connected to the service pipe, and the index reading of which constitutes the basis of charge by the undertaking for gas used on premises where there may or may not be secondary or subsidiary meters.

SPECIFICATION FOR GAS METERS FOR DOMESTIC CONSUMERS

CAPACITY

95. All meters within the normal capacities mentioned hereafter should comply with The Institution of Gas Engineers' Specification for Gas Meters for Domestic Consumers, dated 6th November 1935, endorsed by the Meters Committee of The Institution of Gas Engineers in May 1943.

96. A meter supplied, as complying with this Specification, should be described as conforming with The Institution of Gas Engineers' Specification for Gas Meters for Domestic Consumers and should be designated an "I.G.E. Gas Meter." If so supplied the meter should be legibly stamped "I.G.E."

97. The three sizes of the I.G.E. Gas Meters are termed D. 1, D. 2, D. 4, and the rated capacities specified are 100, 200, and 400 cu. ft. per hour.

98. Should technical development result in increased capacities in relation to size of meter the overall dimensions of the case of the I.G.E. Gas Meter should not be exceeded. It is imperative that present dimensions between the unions should be maintained. Cash boxes with a capacity for £2, 5*s*. and £3 in copper should be standard fitments in the D. 1 and D. 2 meters respectively. All prepayment meters should be fitted with optional two-coin mechanisms.

METER UNIONS

99. Meter unions should accord with *B.S.* 746–1937.

HIGH CAPACITY METERS

CAPACITY

100. The present range of high-capacity meters of 700, 1200, 1800, 3000, 4500, 6000, 9000, and 12,000 cu. ft. per hour respectively are suitable for installation in large buildings.

LANGES

101. The flanges of large meters should be standardised in accordance with Table A of *B.S.* 10, Part I, 1928, and the following table, in which the capacity of the meter is related to the Nominal Pipe Size given in Table A:

B.M. METERS cu. ft. per hour	DRY METERS cu. ft. per hour	NOMINAL PIPE SIZE inches
—	700	2
B.M. 30	1,200 and	3
3,000	1,800	
B.M. 40	3,000 and	4
6,000	4,500	
B.M. 50	6,000 and	6
12,000	9,000	
B.M. 60	12,000 and	8
20,000	15,000	
B.M. 75	20,000 and	10
35,000	25,000	
B.M. 90	—	12
60,000		

METER HOUSING

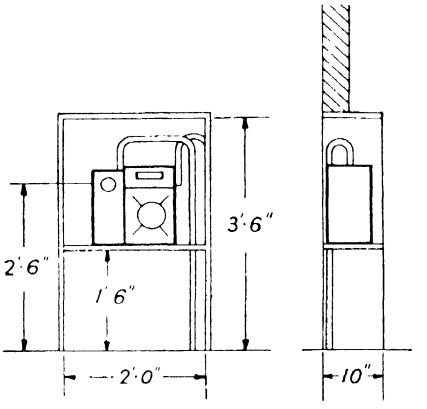
102. In the past no provision has been made normally in building small houses or flats for accommodating gas meters, with the result that they have frequently had to be installed in unsuitable or inaccessible positions. Special attention is, therefore, drawn to the recommendation on suitable housing of meters in post-war buildings, particularly in small dwellings. The gas meter should be housed as near as practicable to the point of entry of the service, and the most suitable position will generally be found in the hall.

The gas service pipe should enter the premises, where economically desirable, as close as practicable to the electricity supply and telecommunications, and the gas and electric meters should preferably be housed adjacent to one another.

103. A ventilated, incombustible compartment of adequate size for the housing of meters should be provided by the building authority, owner, or agent as part of the structure of a building. Where there is a dual compartment, the section for the gas meter should have ventilated doors and, if the electric meter and controls are housed in the same compartment, a partition should be provided between the gas meter and the electric meter. In small dwellings and flats the compartment for the gas meter should have internal dimensions of not less than 2 ft. high by 2 ft. wide by 10 in. deep, and should, where possible, be partly or wholly recessed within the wall. The meter should be so fixed that the coin slot and/or meter index is not less than 2 ft. 6 in. nor more than 3 ft. 6 in. from floor level. The base of the gas meter should, therefore, be not less than 1 ft. 6 in. from floor level.[1]

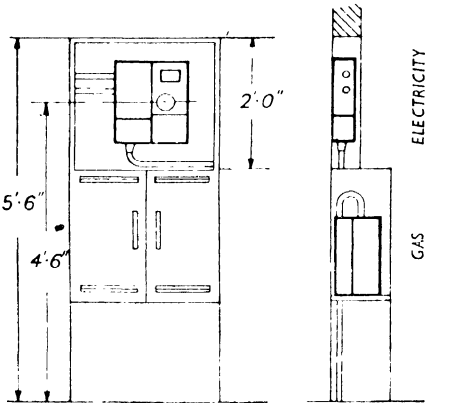
Sketches of suitable arrangements are shown on p. 19.

[1] Attention is drawn to the *London Building Act (Amendment) Act* 1939, Part X, Section 97, relative to the housing of gas meters.



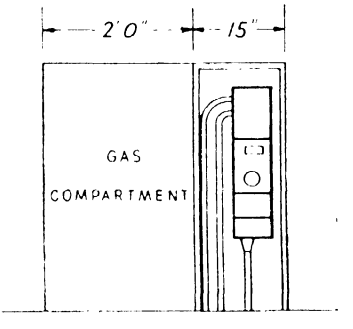
ARRANGEMENT No. 1

The gas meter by itself can be housed in a Ventilated Compartment 3' 6" high, 2' 0" wide, and 10" deep



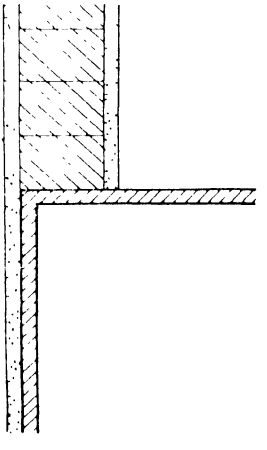
ARRANGEMENT No. 2

The electricity meter is housed above the Gas Meter in a Compartment 2' 0" high as suggested by the Electrical Installations Committee of the I.E.E.



ARRANGEMENT No. 3

Gas Compartment as in 1 and 2 but Electricity Meter and controls housed alongside in compartment 15" wide as suggested alternatively by the I.E.E.



Detail of Method of Building Compartment into $4\frac{1}{2}$" partition wall. Back of box keyed to take plaster

SUGGESTED HOUSING FOR GAS AND ELECTRICITY METERS

POSITION

104. Every primary meter to be used in new premises, or in premises not previously supplied with gas, or with a new or renewed service pipe laid from the main, should be placed as near as practicable to the gas undertaking's main, but within the external wall of the main building; except that, where a separate, specially constructed meter house, or other suitable accommodation for the location and satisfactory protection of the meter is provided outside the building, the meter may be placed in such meter house or accommodation instead of within the premises, subject to reasonable approval by the gas undertaking.

105. Meters should be so fixed that the meter and connecting pipes are prevented by spacing, insulation or other means from coming into contact under any circumstances with electrical conduits or any other conductor.

106. Meters should not be fixed so as to subject them to artificial heat or wide extremes of temperature. Where meters are fitted at floor level, as might be necessary or convenient in large installations, they should be adequately protected.

107. The following locations for meters are specifically prohibited:

a. Immediately above any heating or cooking appliance.
b. In the open.
c. Under draining boards adjoining sinks in houses, or under display slabs in butchers' shops, fishmongers' shops, and similar establishments.
d. In contact with walls.
e. In larders or other places for storage of food.
f. In any other position in which the meter is likely to cause obstruction or to suffer damage or be exposed to conditions likely to affect its accuracy or safety.

FIXING

108. All meters shall be fitted plumb and level. All meters, both primary and subsidiary, should be provided with a cock or valve of a type approved by the gas undertaking. The cock or valve should be in an accessible position and fitted on the service pipe as close as practicable to the inlet connection to the meter. No part of the cock should be less than $\frac{1}{4}$ in. clear of the wall. Where there is a detachable key, it should be retained in position by means of a grub screw or split pin. (See also paragraphs 31 and 79.)

109. Small meters should be securely fitted with lead or lead alloy pipe connections (see *B.S.* 602–1935 *for Lead Pipes* and *B.S.* 603–1941 *for Lead Pipes B.N.F. Ternary Alloy No.* 2), or with other types of connections approved by the gas undertaking, and brass unions complying with *B.S.* 476–1937 for Gas Meter Unions.

110. Meters may be provided with by-passes as the gas undertaking may decide, in a manner approved by it. All such meters should be fitted with approved types of inlet, outlet, and by-pass cocks or valves. Where connections to meters are rigid, provision should be made to facilitate final adjustment and easy disconnection. The by-pass valve should be secured in a manner approved by and should bear the seal of and be sealed by the gas undertaking.

111. Any meter upon which the charge for gas is based should be fixed on the authority and under the supervision of the gas undertaking, and the position and size of such meter should be approved by the gas undertaking.

SECTION 3. GAS APPLIANCES

112. In considering the initial equipment of a building, a decision has to be made on the type of fuel to be used for cooking, space heating, water heating, laundry (including clothes drying), refrigeration and lighting, or on the type of fuel-burning appliances to be installed as part of the equipment of the building.

113. Whereas these matters usually receive full consideration in the planning of large and specialised buildings, they are too often neglected in planning small dwellings.

114. Both the installation and the design of gas appliances have frequently in the past been marred by the fact that in the majority of cases they have had to be installed either as additions to existing solid fuel appliances (as in the case of gas fires added to coal grates) or they have had to be fixed in positions which were not primarily or adequately designed for their reception.

115. If certain general provisions are made, whatever form of fuel is finally selected, the appropriate type of appliance could be installed without causing unnecessary alteration or leading to incongruity. The Committee recommends that the Standards Committee of the Ministry of Works give careful consideration to this matter in consultation with the gas, electrical and solid fuel industries, with a view to determining suitable locations and dimensions for domestic fuel appliances (for example, suitable dimensions of fireplaces) which would result in the harmonious fitting therein of appliances for any fuel service at the choice of the occupier.

116. If dimensions were standardised, the number of sizes of gas, electric, coal, coke or other solid fuel appliances could be limited, and one type of appliance could be easily changed for another without upsetting design details. It would also facilitate the manufacture of the necessary refractory linings for the fire opening. It is recommended, therefore, that certain standard dimensions be included in the plans of all small dwellings.

117. The Committee, in conjunction with the other fuel interests, has consulted the Sub-Committee on Design of Houses and Flats of the Ministry of Health and has submitted proposals for the location, dimensions, and installation of fuel appliances in new buildings. A selected list of gas and coke burning appliances for single family dwellings is given in Appendix A.

COOKING APPLIANCES

118. A site with a floor area of at least 2 ft. 6 in. wide by 2 ft. deep, suitable for the reception of a domestic gas cooker of the vertical (single unit) type, or at least 4 ft. wide by 2 ft. deep for a cooker of the horizontal (two unit) type, should normally be provided in the kitchen. The site should be convenient for use, well lighted, free from draughts, and in such a position that adequate ventilation may be provided for the removal of vapours and cooking odours. (See paragraph 141.) Sufficient air space, or similar effective thermal insulation, should be provided between the cooking appliance and the adjacent building material, cupboards and the like. The adjacent walls and floors should be so finished by tiling or other suitable means that they may be easily cleansed from the spray of cooking fats and accidental spillage. Where cookers are to be built-in, in line with other kitchen equipment, the cookers should be 1 ft. 9 in. or 3 ft. 6 in. in width, and the hot plate 1 ft. 9 in. in depth. (See illustration on p. 22.)

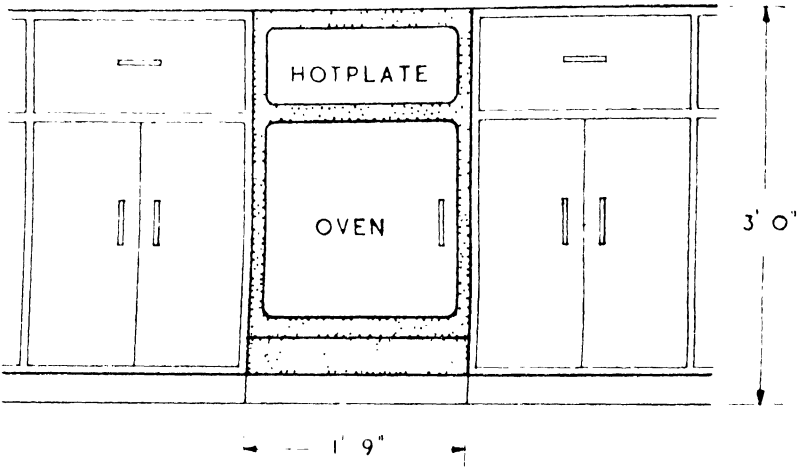


FIG. 1—VERTICAL TYPE

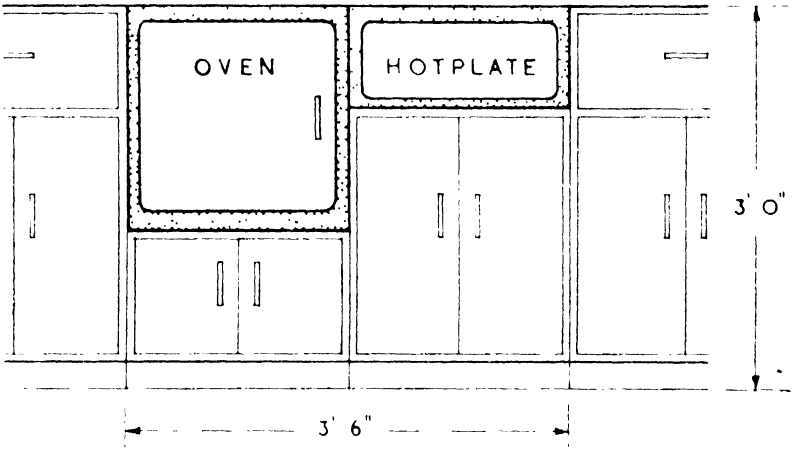


FIG. 2—HORIZONTAL TYPE

ELEVATIONS SHOWING SPACE REQUIRED FOR GAS COOKERS IN KITCHENS OF SMALL FAMILY DWELLINGS

WATER HEATING APPLIANCES

WATER SUPPLY

119. Pipes and fittings, storage vessels and the like used in the water supply should comply with the requirements of appropriate Codes of Practice relating to water supply.

120. To ensure constant pressure the water supply should preferably be taken from a storage cistern, but care should be taken to ensure that the cistern is of ample capacity, and is sufficiently high to give the required working pressure, after allowing for the normal loss of pressure from the pipes and fittings.

121. When a gas water heater is connected directly to a main supply both the inlet and outlet distributing pipes should be of the strength specified in the appropriate Codes of Practice for water supply for mains pressure and not that for cistern supply.

122. To conserve fuel and to ensure efficient working, all hot-water pipes and storage vessels should, wherever possible, be effectively insulated by lagging.

123. A gas water heater that is to be interconnected with a boiler system should in all cases be supplied from the cold water cistern and not directly from a pipe subject to mains pressure.

124. An approved stop cock should be fitted on the cold water supply in the vicinity of the gas water heater for maintenance purposes.

INSTALLATION

125. The various types of gas water heaters, adapted for different systems of water supply and draw-off connections and for different usages of hot water, make it impracticable to set forth recommendations which will cover the installation of each different type. To enable gas water heaters of any type to be installed, if desired, adequate provision should be made at the outset for easy connection to the gas installation pipes. More detailed information on the installation of water heaters will, it is hoped, be incorporated in the relevant Code of Practice. Recommendations regarding flues for gas appliances are given in paragraphs 132 to 140.

SPACE HEATING APPLIANCES

FIRES

126. Where a gas fire is to be fitted on a floor not formed of fire-resisting material conforming with *B.S.* 476–1932, there should be laid flush with or on the floor a hearth or slab of incombustible material which conforms with the British Standard, or some equally satisfactory insulation. The hearth should be of such thickness as will afford sufficient strength combined with satisfactory insulation. It should extend for a distance of at least 12 in. in front of the fire, and 6 in. on each side of the fire.

127. Excluded from this recommendation are:

a. Gas fires the flames of which are 9 in. or more from the floor level.

b. Gas fires with raised metal hearths of which the overall height is not less than $1\frac{1}{2}$ in. and the forward projection not less than 10 in.

128. The hearth should not be obstructed by irremovable raised projections. The jambs and lintel of the fire opening should be in one plane and unobstructed by projecting keystones or bosses.

129. Draught canopies of solid fuel grates, if fitted, should be removable and, when removed, should leave no projection beyond the plane of the framework of the fire opening.

RADIATORS AND PORTABLE HEATERS (NON-VENTILATING TYPES)

130. Points for portable heaters should be fitted with a tap of the bayonet fitting plug type complying with *B.S.* 570-1934, or with a suitable safety device which must have the approval of the gas undertaking. When flexible metallic piping is used it should conform with *B.S.* 669-1936 or be approved by the gas undertaking. (See also paragraph 88.)

REFRIGERATORS

131. A suitable space should be provided for the installation of a gas-operated refrigerator, if required, so as to give a clear ventilated air space above and around the cabinet, whether of the independent or built-in type.

FLUES FOR GAS APPLIANCES

The following are general recommendations relating to flues for gas appliances:

132. Every flue which is part of the structure of the building and to which gas fires may be connected should have a cross-sectional area of not less than 20 sq. in., be not less than 2½ in. on a horizontal section, and in any case not less than the cross-sectional area of the flue outlet of the appliance. The area of the flue should not be restricted, for example, by the intrusion of jointing material.

133. Flues in which condensation of water vapour may occur should be of material which will prevent seepage of moisture through their walls.

134. Flue connections and free-standing flues, such as those passing through a roof space, should conform with the appropriate British Standard, *i.e. B.S.* 41-1908, *Cast-iron Flue or Smoke Pipe, Spigot and Socket; B.S.* 567-1934, *Asbestos Cement Spigot and Socket Flue Pipes and Fittings for Gas Fired Appliances; B.S.* 715-1936, *Sheet Metal Cylindrical Flue Pipes, Fittings and Accessories for Gas Fired Appliances.*

135. Flue connections and free-standing flues should be so fixed as to provide a sufficient air space or other effective thermal insulation between them and the adjacent building material, unless the latter is incombustible.

136. Flues should terminate above roof level in a position to ensure their correct functioning under normal weather conditions. When the flue has to be terminated on the face of a wall, the design of the terminal should be such as to take advantage of the air movement to achieve updraught in the flue.

137. Terminals should comply with the recommendations contained in *B.S.* 766-1938.

138. The following types of gas water-heating appliances should be connected to flues:

a. Rapid (or "Instantaneous") Water-heating Type, used for the heating of water for a bath or other purpose requiring a similar volume of hot water.
b. Storage (or "Circulator") Type, having gas burners generating 15,000 B.Th.U. (gross) per hour or more.
c. Central Heating Type.
d. Wash Boilers, Washing Machines or similar appliances, having gas burners generating more than 20,000 B.Th.U. (gross) per hour.
e. Any appliance fitted in a bathroom for heating water for a bath, having gas burners generating more than 500 B.Th.U. (gross) per hour per 35 cu. ft. of room space. Every such bathroom should be provided with adequate means of ventilation to the outside of the room.

GAS APPLIANCES

139. A water-heating appliance connected to a flue should include an efficient baffler or draught diverter complying with *B.S.* 766–1938, either as an integral part of the heater, or fitted not more than 12 in. above the outlet of the appliance and within the same room.

140. The connection between the flue outlet of the appliance and a flue which is part of the structure of the building, or which is rigidly supported, should, unless impracticable, incorporate a slip socket to facilitate disconnection.

RECOMMENDATION

141. It is recommended that special provision be made in kitchens for adequate ventilation to ensure the necessary air changes for the removal of odours, due to cooking, washing, etc., and so to prevent their permeating the house.

SECTION 4

GAS INSTALLATION IN A TYPICAL SCHOOL, AND FOR DOMESTIC SCIENCE CENTRES

142. The recommendations which follow are submitted after a study of a typical plan, provided by the School Buildings Committee, for a single-storey school to accommodate 360 pupils. It is to be noted that they would require modification according to the type and purposes of the school.

143. The workmanship and materials should be in accordance with the foregoing recommendations for gas installations in post-war buildings.

144. It has been assumed that the size of domestic science classes will average and not exceed 20 pupils, and it has also been taken as an accepted principle that the pupils should be taught to use such appliances as they are likely to have to use in their homes either at the present time or in the near future.

145. The patterns installed should in general represent good average present-day practice with some modifications (referred to in detail subsequently) to make them more convenient for instructional purposes. The local Education Authorities will have regard to the patterns predominating in their districts.

SERVICE PIPE

146. The size and position of the gas service pipe to the building should be arranged with the gas undertaking and it should be sufficient to provide a minimum hourly demand of 20 therms. (This does not take account of the additional demand necessary for central heating or domestic hot water.)

METERS AND ENCLOSURE

147. Accommodation should be provided either by addition to, or within the structure, and of sufficient size to house meter(s) of the requisite hourly capacity. One unit space on the type plan would be sufficient for this purpose. It should allow of easy access for the installation and removal of meters.

INTERNAL INSTALLATIONS

148. The internal installations should be planned, laid and fixed so as to conform in all respects with the general recommendations for gas installations.

149. The principal installation pipes and branches therefrom should be accommodated separately or with other utility services in ducts formed in the floors of rooms and corridors. Extensions to appliances in the rooms should be accommodated in ducts or chases, dependent upon the method of construction of the building.

150. Branch installation pipes should be extended into all rooms and the minimum sizes at the outlets should conform with the following table:

LOCATION	IF WITH LIGHTING	IF WITHOUT LIGHTING
	Inches	Inches
Classroom	$\frac{3}{4}$	$\frac{1}{2}$
Practical room	$1\frac{1}{4}$	1
Domestic science room	$1\frac{1}{4}$	$1\frac{1}{4}$
Art room	1	1
Library	$\frac{3}{4}$	$\frac{1}{2}$
Medical inspection room	$\frac{3}{4}$	$\frac{3}{4}$
Principal's room	$\frac{1}{2}$	$\frac{1}{2}$
Common room	$\frac{3}{4}$	$\frac{3}{4}$
Hall	1	$\frac{3}{4}$
Hall (stage)	$1\frac{1}{4}$	$1\frac{1}{4}$
Cloakrooms	$\frac{3}{4}$	$\frac{1}{2}$
Lavatories	$\frac{3}{4}$	$\frac{3}{4}$
Gymnasium	1	$\frac{3}{4}$
Gymnasium clothes drying room	$\frac{3}{4}$	$\frac{3}{4}$
Gymnasium changing room	$\frac{3}{4}$	$\frac{3}{4}$
Meals' kitchen	2	2
Boiler-house	$\frac{3}{4}$	$\frac{3}{4}$
Stores	$\frac{1}{2}$	—

151. The sizes specified in the above table allow for the installation of a modern system of gas lighting, but it has been assumed that consideration of the detailed planning of such a system would be a matter for the Committee on the Lighting of Buildings.

152. The employment of gas for central heating should receive consideration in the early stages of planning, as this will have a bearing upon the size of gas service to the building, dimensions of enclosure for meters and the space allowed for the boiler-room and ancillary accommodation.

153. This would necessitate some replanning of the space allowed for fuel storage and boiler accommodation, as neither the storage nor handling of fuel nor the removal of ash need be provided for. The layout of the heating circuits could also be viewed from the standpoint of complete automatic temperature control.

154. Occasional heating will be required at certain seasons, and this is provided for by the equipment recommended for the staff rooms and medical inspection room.

INSTALLATION IN A SCHOOL

WATER HEATING

155. As the demand for hot water will be variable and is primarily required in the kitchen, lavatories, gymnasium and other changing rooms—rooms widely separated—it is necessary that the system should be flexible. Economy in both installation costs and in heat loss from circulating pipes would result from installing separate storage units: one in the boiler-room to serve the kitchen, one in the lavatories to serve the wash-hand basins and showers in the changing room.

156. In addition to those demands for hot water a similar economy can be achieved by the provision of an independent unit in the cloakroom to serve the coat rails and drying chambers.

GAS-HEATED EQUIPMENT

157. The equipment specified conforms with established good practice and has been evolved from investigation and tests made in collaboration with county education authorities and their staffs. The appliances suggested below for installation in the meals' kitchen should be constructed of such materials and be in such finishes as will present a clean and pleasing appearance, be labour saving, and provide a flexible and speedy service owing to their wide range of heat control.

MEALS' KITCHEN

158. The following gas appliances are recommended for the meals' kitchen:

i. Two steamers each fitted with 6 wire baskets and automatic water-feed cistern. Internal dimensions 24 in. high by 18 in. wide by 24 in. deep.

ii. Two 30-gallon vegetable boilers with counter-balanced lids fitted with concentric burners and 1-in. emptying cocks with clearing plugs.

iii. One 20-gallon milk and porridge boiler with heavily tinned copper pans, the inner one removable, the jacket fitted with automatic filling system, emptying tap, water gauge and steam outlet.

iv. Two ovens mounted on a stand 24 in. high with a pan rack under same. Internal dimensions of each oven 28 in. high by 21 in. wide by 24 in. deep. In some instances three ovens of similar total capacity may be required depending upon the type of meals to be prepared.

v. One 5-foot-long hotplate mounted on a stand comprising 3 large and 8 small boiling burners. Overall dimensions 30 in. high by 63 in. wide by 30 in. deep.

vi. One hot cupboard with sliding doors on both sides and single polished stainless steel top, fitted with two shelves, safety tap and swing-in pilot lighter. Overall dimensions of cupboard 36 in. high by 72 in. wide and 24 in. deep.

Note.—Where it is the practice to serve the complete course upon the plate increased hot cupboard accommodation will be required.

vii. One refrigerator (double compartment), internal capacity to 10 cu. ft. and shelf area of 17·8 sq. ft.; overall dimensions 4 ft. 10 in. high by 3 ft. 8 in. wide by 2 ft. 4½ in. deep.

viii. One temperature controlled bottled milk warmer made up of units, each unit accommodating two standard wire baskets holding 60 bottles. Overall dimensions of unit 24 in. high by 30 in. wide by 20½ in. deep.

VENTILATION OF KITCHEN

159. The comfort of the working staff in a kitchen is aided by the collection and removal to external air of cooking and steam vapours. Provision for this should be made in the planning by centrally grouping, as far as may be practicable, ovens, steamers and boilers under the lantern light to which a suitable collecting canopy should be fitted.

MEDICAL INSPECTION ROOM

160. The following gas appliances are recommended for the medical inspection room:

i. One fire, preferably of the radiant panel type.
ii. One single-point water heater with output capacity of at least one-half gallon of water per minute raised through 100° F.
iii. One instrument steriliser with draw-off tap, the whole in chromium plate finish, mounted on stand. Overall dimensions 36 in. high by 20 in. wide by 9 in. deep.

PRINCIPAL'S ROOM

161. The following gas appliances are recommended for the principal's room:

i. One fire connected to a prepared opening and flue built into the structure.
ii. One single-point water heater with output capacity of at least one-half gallon of water per minute raised through 100° F.

COMMON ROOM AND LOBBY

162. The following gas appliances are recommended for the common room and lobby:

i. One fire, preferably of the radiant panel type, connected to a prepared opening and flue built into the structure.
ii. One single-point water heater with output capacity of at least one-half gallon of water per minute raised through 100° F.
iii. One domestic cooking stove, comprising oven ($15\frac{1}{2}$ in. wide) and hotplate with plate rack and back. Overall dimensions 36 in. high by 24 in. wide by 21 in. deep, excluding plate rack and back.
iv. One temperature controlled gas-heated clothes drying cabinet. Overall dimensions 6 ft. 3 in. high by 27 in. wide by 25 in. deep and suitably ventilated.

GYMNASIUM (CLOTHES DRYING ROOM)

163. One temperature controlled gas-heated clothes drying cabinet. Overall dimensions 6 ft. 3 in. high by 6 ft. wide by 2 ft. 1 in. deep is recommended.

HOUSECRAFT ROOMS

164. As the number of pupils who can work conveniently and safely at each cooker hotplate is limited, additional two-burner hotplates (without ovens) should be provided and fixed upon or recessed into the tables. In the latter case a removable top should be provided.

165. The gas cookers should be finished in porcelain enamel, preferably mottled and white, and one at least should be fitted with a glass-panelled door. This last recommendation is not in the nature of a forecast that in the future all cookers are likely to have glass doors, but is based upon experience of their usefulness for teaching purposes, and for preventing one pupil spoiling the work of another by opening the oven door to see how her own dish is progressing.

166. The cookers should be fitted with thermostats. Oven taps should have drop thumbpieces, or other safety device, to prevent their being accidentally turned on.

167. The cookers should be spaced for free access to the front and both sides and should not be set back into the benches. They should be spaced at least 2 ft. 6 in. apart. The additional separate hotplates on the tables should each be fitted with two boiling burners and a white enamelled spillage tray. They should be finished in mottled porcelain enamel and should preferably be rigidly connected. Where the tables are required for other purposes, the appliances should be connected by $\frac{5}{16}$-in. flexible metallic tubing (*B.S.* 669-1936) to plug-in bayonet-fitting connections.

168. A gas-operated refrigerator should be provided, which should not be placed within the larder.

169. For laundry work, one 10-gallon gas-heated washboiler with tinned copper pan and one gas-heated hand washing machine with hand wringer attached should be provided, and one gas-heated clothes dryer and airer, 6 ft. high by 5 ft. wide by 2 ft. deep, with double doors and swing-out clothes rails. These latter should be rust-proof and preferably adjustable as to height within the cabinet.

170. Experience has shown that for young pupils the use of internally heated flat smoothing irons without flexible attachment is preferred. One or more gas-iron heaters, comprising stand with ventilated hood to accommodate the required number of sets of $3\frac{1}{2}$ or 4 lb. internally heated irons, arranged in two tiers with shelf under for spare irons, should be provided in positions convenient for connection to the flue or flues. The lower tier of the irons should not exceed 2 ft. from the floor so that the irons may be lifted without undue strain. So that irons and other small portable appliances may be demonstrated, a minimum of two plug-in connections should be provided on or in the floor under the demonstration table.

171. Although a hot-water supply may be available from the general supply for the whole school, it is recommended both for convenience (when the general supply is shut down) and purpose of instruction that an independent system be installed. This may be provided by a domestic pattern coke boiler with gas burner ignition fixed adjacent to the coal range and flued into the same chimney. The boiler should feed into a 60-gallon lagged storage cylinder which should have connections to a gas circulator water heater with an hourly gas input not exceeding 30,000 B.Th.U. The connections should be fitted with an "economy" valve so that one-third of the storage capacity may be used if desired.

172. An alternative is a combined gas water heater and 60-gallon storage cylinder, with "range connections," connected either to an independent coke boiler or to a back boiler behind the coal range. Here again the local education authority should be guided by the good practice most common in their area. Either system must, of course, be fed from an overhead storage cistern and be provided with an expansion pipe. The feed pipe, expansion pipe and circulating pipes should be visible to the pupils for instructional purposes.

173. The combined water heater and storage cylinder, or an independent water heater of, say, 40,000 B.Th.U. hourly gas input feeding into the storage cylinder, may be automatically controlled by a clock controller so that it will be lit and extinguished at pre-determined times on particular days of the week.

174. The gas installation pipe to the appliances should be $1\frac{1}{4}$ in. diameter running right round the room near the wall and an inner ring within the tables of $\frac{1}{2}$-in. pipe. These should be easily accessible in ducts in the floor and provided with suitable fittings for easy disconnection of each length. Spare plugged tees should be provided at intervals.

DEMONSTRATION FLAT

175. This will lose verisimilitude for the majority of pupils if the general heating and the hot-water supply is from a hidden central source.

176. It is suggested that the hot water be provided by a multipoint instantaneous gas water heater fixed in the kitchen and provided with an independent flue in the stack. It should have draw-off connections to the bath, lavatory basin and sink. The gas installation pipe should be 1 in. internal diameter, and the hot-water pipes and the cold-water feed pipe $\frac{3}{4}$ in. if from a storage cistern supply and $\frac{1}{2}$ in. if direct from the mains supply.

177. A portable gas heater with a gas rate of 6 cu. ft. per hour should be provided in the kitchen and a gas heater of the wall-bracket type with a gas rate of 5 cu. ft. per hour fixed in the bathroom.

178. A gas fire should be fixed in the bedroom and living room (and the bed-sitting room, if provided) for "topping up" the central heating by providing radiant heat comfort.

179. A gas-heated washing machine, of the folding wringer type, should be provided in the kitchen.

180. It is recommended that at least one large-dial demonstration gas meter be fitted in the demonstration flat or housecraft room for the purpose of instructing pupils in the amount of gas consumed for various uses.

NEEDLEWORK ROOM

181. Irons will be required for pressing, embroidery transfers, etc., and internally heated iron sets (of the type specified for housecraft rooms) should be fitted in convenient positions on the walls to provide as many irons as may be required.

PRACTICAL ROOMS

182. In each practical room which is to be used as a laboratory the branch installation pipe should be fitted with a sectional control by means of a cock or valve on or near to the demonstration bench.

183. Each bench should be fitted with a cock to give local control. The regulation and control of each bunsen burner or apparatus is facilitated if the tap which controls it is fitted at the front of the bench. The taps should be so fitted or of such type that they cannot be accidentally operated.

184. Bayonet-fitting plugs and sockets fitted at the rear of the benches ensure a simple and safe coupling and a clear surface when the apparatus is removed.

185. In the practical rooms, which may be used as manual instruction or handicraft rooms or hobbies rooms, the equipment will depend upon the district and curriculum, and sufficient spare plugged tees should be provided on the 1-in. diameter gas installation pipe, which should be carried right round the room, to provide for appliances such as glue-pot heaters, soldering iron heaters, forges or pottery kilns which may be required.

186. Where small supplies may be required for portable appliances to be used on removable tables or benches, $\frac{1}{2}$-in. gas installation pipes should be run in ducts across the floor and fitted with bayonet-fitting plugs and sockets each with an independent cock and contained under a trap finished level with the floor.

R. J. ROGERS,
Chairman of Committee.

APPENDIX A

SELECTED LIST OF GAS AND COKE BURNING APPLIANCES FOR SINGLE FAMILY DWELLINGS

GENERAL REQUIREMENTS

187. All appliances should conform with the appropriate British Standards in respect of performance and combustion standards.

188. The external finish should be durable and not subject to excessive deterioration in normal use.

189. The appliance should be designed to have an efficient working life of ten years subject to one maintenance visit per annum. (Except where special conditions may make more frequent maintenance necessary.)

190. Access for maintenance should be simple and parts likely to need replacement, as far as practicable, should be of standard size and design.

191. Sizes of gas, water and flue connections should be standard.

192. No danger in operation should arise from wear and tear due to normal use.

193. No surface likely to be touched accidentally should exceed 120° C.

194. All taps should be protected against accidental operation.

LIST OF APPLIANCES

195. This list is not final, both the items and the specifications requiring further consultation and agreement between gas undertakings and appliance makers. The agreed list will still need periodic revision to ensure that it represents up-to-date practice.

i. Cooker A.
ii. Cooker B.
iii. Cooker C.
iv. Bath Water Heater.
v. Sink Water Heater.
vi. Multipoint Water Heater.
vii. Storage Water Heater.
viii. Coke-fired Water Heater.
ix. Gas Circulator Water Heater.
x. Coke- or gas-fired Water Heater.
xi. Inset living room fire (gas).
xii. Inset living room fire (coke).
xiii. Independent living room fire (gas).
xiv. Independent living room fire (coke).
xv. Occasional gas fire (inset).
xvi. Occasional gas fire (Panel Type).
xvii. Portable Heater (Non-Ventilating Type).
xviii. Heater for hall or kitchen (Non-Ventilating Type).
xix. Floor-level Heater.
xx. Wash Copper.
xxi. Refrigerator.
xxii. Clothes Dryer.
xxiii. Gas-fired Ignition Device for solid fuel grates (*e.g.* gas poker).

196. If desired, horizontal type (two unit) cookers can be provided. (See illustration on p. 22.)

BRIEF SPECIFICATION OF APPLIANCES

97. Further discussion and amplification are required of the performance specifications and development work in respect of items marked *.

i. COOKER A

Oven size : Door opening 14 in. high by 15½ in. wide ; depth 14 in. Hotplate height 36 in. Oven fitted with thermostat. Oven grids to have effective cooking area 173 sq. in. each, and to carry stops preventing dishes projecting outside this area. Two grids provided. Hotplate to have three boiling burners and a griller.

Maximum consumption of all 45,000 B.Th.U. per hour and of largest 15,000 B.Th.U. per hour

Grill frets of composite cast iron and heat-resisting steel.

Fixed injectors with governed gas supply.

Point for fixing gas lighter.

Levelling device on legs.

Standard meat tin, cake tray, and grill pan and grill provided.

ii. COOKER B

Same as Cooker A, but with oven 16 in. high.

iii. COOKER C

Same as Cooker A, but with oven 18 in. high, three grids to oven, four boiling burners and griller with consumption of 55,000 B.Th.U. per hour.

iv. BATH WATER HEATER

Consumption 100,000 B.Th.U. per hour.

v. SINK WATER HEATER

If instantaneous, with consumption 40,000 B.Th.U. per hour. Consumption 6000 B.Th.U. per hour if of storage type.

vi. MULTIPOINT WATER HEATER

Consumption not exceeding 125,000 B.Th.U. per hour.

vii. STORAGE WATER HEATER

Consumption 20,000 B.Th.U. per hour. Construction integral with storage cylinder not less than 20 gallons.

viii. COKE-FIRED WATER HEATER

Imparting 20,000 B.Th.U. per hour to water with a coke consumption of 3 lb. per hour and capable of remaining alight at a consumption of 0·5 lb. per hour.

ix. GAS CIRCULATOR WATER HEATER

Consumption not exceeding 30,000 B.Th.U. per hour.

*x. COKE- OR GAS-FIRED WATER HEATER

Appliances of this type have not hitherto been generally available. Various arrangements are possible and it is undesirable to specify rigidly at the present stage. The appliance might take the form of a combination of vii. and ix. above, or alternatively could be designed to operate primarily as a closed stove on coke in winter, taking surplus heat into a lagged storage tank which in summer would be directly heated by gas at a relatively low gas rate.

*xi. INSET LIVING ROOM FIRE (GAS)

Distribution of radiant heat suitable for long-period use. Available as sizes a. and b. with the following performances :

SIZE	FULL OUTPUT B.TH.U. PER HOUR		REDUCED OUTPUT B.TH.U. PER HOUR	
	RADIANT HEAT EMITTED	GAS CONSUMPTION	RADIANT HEAT EMITTED	GAS CONSUMPTION
a.	7,000	16,000	3,000	9,000
b.	9,000	20,000	4,000	10,000

Appearance to be good at specified reduced output.

xii. INSET LIVING ROOM FIRE (COKE)

To consume 2 lb. coke per hour, giving a radiant heat output of 7200 B.Th.U. per hour.

*xiii. INDEPENDENT LIVING ROOM FIRE (GAS)

To combine radiant fire with output of 5000 B Th.U. per hour with air heater of 3500 B.Th.U. per hour. Radiant and air heater should preferably be capable of operation either together or separately.

xiv. INDEPENDENT LIVING ROOM FIRE (COKE)

To act as open fire or closed stove, burning 2 lb. coke per hour open and 0·5 lb. closed, with heat output (radiation and convection) of 8400 B.Th.U. per hour in first case and 3000 B.Th.U. per hour in second.

xv. OCCASIONAL GAS FIRE (INSET)

Available in three sizes, a., b. and c., with the following performances :

SIZE	FULL OUTPUT B.TH.U. PER HOUR		REDUCED OUTPUT B.TH.U. PER HOUR		EMISSION IN 15 MIN. FROM COLD. FULL GAS RATE B.TH.U. PER HOUR
	RADIANT HEAT EMITTED	GAS CONSUMPTION	RADIANT HEAT EMITTED	GAS CONSUMPTION	
a.	5,000	12,000	2,500	7,500	4,200
b.	7,000	16,000	3,000	9,000	6,000
c.	9,000	20,000	4,000	10,000	7,800

xvi. OCCASIONAL GAS FIRE (PANEL TYPE)

Available in sizes and performances specified in xv. above.

xvii. PORTABLE HEATER (NON-VENTILATING TYPE)

Consumption 6000 B.Th.U. per hour with approximately 1500 B.Th.U. per hour emitted as radiant heat.

xviii. HEATER FOR HALL OR KITCHEN (NON-VENTILATING TYPE)

Consumption 5000 B.Th.U. per hour ; no radiation component necessary.

xix. FLOOR-LEVEL HEATER

Unit construction, consuming 2500 B.Th.U. per hour per unit, inducing ventilation from below floor and giving dilution of products in induced air of not less than 20 : 1.

xx. WASH COPPER

a. Flued type with a consumption not exceeding 30,000 B.Th.U. per hour.
b. Flueless type, intended to be filled initially from hot-water supply, with a consumption not exceeding 12,500 B.Th.U. per hour.
c. Washing machine incorporating electrically driven mechanism with flueless type copper (b) above.

All models should be provided with easy means of ignition.

xxi. REFRIGERATOR

2·2 cu. ft. storage space.

*xxii. CLOTHES DRYER

Air-heating device for incorporation in clothes-drying cupboard having adequate ventilation to outside air. Gas consumption 10,000 B.Th.U. per hour. Flame adequately housed and heating gases diluted to protect clothes from scorching.

xxiii. GAS-FIRED IGNITION DEVICE FOR SOLID FUEL GRATES (*E.G.* GAS POKER)

These may be in the form of

a. Gas burner integral with the grate, as is common with all types of coke-burning grate.
b. Gas poker, for attachment by means of a plug and socket connection, for igniting any appliance burning solid fuel.

APPENDIX B

"BOTTLED" GAS (BUTANE, PROPANE, Etc.) INSTALLATIONS

INTRODUCTION

198. The term "Bottled" Gas is used in this Report to denote hydrocarbon gases such as butane or propane stored in liquid form under pressure. The release of this pressure allows the liquid to assume a gaseous form. In one type, the gas is stored in containers of two sizes, the smaller being 12½ in. high by 13 in. diameter and the larger 23 in. high by 13 in. diameter. The larger container, when empty, weighs about 28 lb. In an unused container the contents are under a pressure of 23 lb. per sq. in. One proprietary type of container (used for "Calor" gas) holds 32 lb. of liquefied gas, equivalent to 215 cu. ft. of free gas having a calorific value of 3200 B.Th.U. per cu. ft. This gas has twice the density of air. As a safety precaution, "bottled" gas should be made odoriferous with a non-toxic odorant. "Bottled" gas is said to be "non-poisonous."

CONTAINERS

199. A standard installation consists of two containers, a pressure regulator and a parallel connector or automatic change-over switch.

MATERIAL

200. There are at present no regulations or British Standard for containers for "bottled" gas, but it is understood that a specification is being prepared by the Gas Cylinders and Containers Committee, appointed by the Department of Scientific and Industrial Research at the request of the Home Office. It is recommended that the Home Office be requested that the issue of this specification be expedited with a view to the preparation of a British Standard based on these official recommendations. In the meantime, designs of proposed containers for "bottled" gas should be forwarded to H.M. Inspector of Explosives, Home Office, who may require sample containers to be tested before manufacture of the containers in bulk is commenced.

FITTINGS

201. Every container, when delivered, must have a covering cap, generally in the form of a carrying handle, to protect the container valve and cover the outlet safety cap. The container valve must be of such a design as to prevent leakage of gas round the spindle.

LOCATION

202. The container should be fixed at ground-floor level and as near as possible to the appliances to be supplied. A basement should be avoided, and the containers must not be placed in cupboards, under stairs, or in any place where there is not a free circulation of air. They must not be placed near any source of heat, and places where considerable fluctuations in temperature take place must be avoided. If the container has to be placed out of doors or in a shed, it must be protected from the cold so as to maintain a temperature similar to that maintained in the house, but it should not be wrapped in such a way as to prevent free circulation of air around it.

203. Containers must be operated in a vertical position and must not be used when in a horizontal position.

INSTALLATION PIPES

SIZE

204. The standard pipe used is $\frac{3}{8}$ in. diameter. Sizes down to $\frac{1}{4}$ in. can be used.

When making the original installation in a house, possible extensions should be borne in mind, and the installation should be carried out in such a manner that extensions can be added without taking down work done previously. If it is anticipated that the town gas mains will be extended to a house in which "bottled" gas is being installed, the installation pipes should be of a size sufficient to carry the town gas when it becomes available.

205. Since the maintenance of the correct pressure at the appliance is essential for good combustion, the bore of the pipe must on no account be restricted. As the injector nipples on all "bottled" gas appliances are very small, all dust and dirt should be very thoroughly removed from all pipes and connections before being installed.

206. The following table indicates pipe sizes for use with "bottled" gas at the standard regulated pressure of 10 to 12 in. w.g.:

TABLE OF PIPE SIZES (INCHES)

LENGTH OF PIPE IN FEET	CONSUMPTION PER HOUR IN CUBIC FEET					
	2	3·5	7	10	14	18
16	$\frac{1}{4}$	$\frac{1}{4}$	$\frac{1}{4}$	$\frac{1}{4}$	$\frac{3}{8}$	$\frac{3}{8}$
32	$\frac{1}{4}$	$\frac{1}{4}$	$\frac{1}{4}$	$\frac{1}{4}$	$\frac{3}{8}$	$\frac{3}{8}$
50	$\frac{1}{4}$	$\frac{1}{4}$	$\frac{1}{4}$	$\frac{3}{8}$	$\frac{3}{8}$	$\frac{3}{8}$
65	$\frac{1}{4}$	$\frac{1}{4}$	$\frac{1}{4}$	$\frac{3}{8}$	$\frac{3}{8}$	$\frac{1}{2}$
85	$\frac{1}{4}$	$\frac{1}{4}$	$\frac{3}{8}$	$\frac{3}{8}$	$\frac{3}{8}$	$\frac{1}{2}$

MATERIAL

207. Solid drawn copper pipe is preferred, but any pipe, other than rubber, as used for installation pipes by the gas industry, is suitable provided tight joints can be made.

208. Where flexible tubing is used for connecting a portable appliance a cock should be fixed in the permanent installation pipe at the inlet to the flexible pipe. No cock should be fitted to appliances so used, but portable appliances with taps for the control of individual burners should be connected with metal pipe and unions for easy disconnection if required.

JOINTS

209. All screwed joints should be made up with a jointing compound that has proved suitable for the gas. All screwed pipes should have clear-cut threads. Red

lead paint must not be used. When available, litharge and glycerine or suitable proprietary compounds and glycerine mixed to a stiff paint may be used. No jointing compound should be allowed to get into the pipes. A satisfactory material suitable for use with " Calor " gas and known as " Calor Gas Compound " is obtainable from the Calor Gas (Distributing) Company Limited.

210. With copper pipe either compression or soldered joints are satisfactory. Lighting fitting connections should be brazed.

211. For houses, and where the installation is likely to be permanent, the connection between the container and pipes and between the pipes and the appliances should be made by means of appropriate metal fittings, and short lengths of rubber pipe must not be used.

CONTROL

212. " Bottled " gas equipment is adjusted to work at a pressure of from 10 to 12 in. w.g. This pressure is governed and maintained by a gas pressure regulator or governor fixed on the container outlet. The diaphragm of this regulator must be of an approved fabric resistant to the action of the gas. In the " Calor " gas regulator the union nut has a left-hand thread. The regulator must be of a type which will shut off completely and not permit any gas creep.

213. To prevent loss of gas from the pipe system when a container has to be exchanged a cock or valve should be placed adjacent to the regulator.

214. When joining two or more containers in parallel a regulator can be attached to each container, or one regulator can be fitted on the outlet of a common connector.

215. In a new installation all joints and taps at appliances should be tested for soundness at a pressure of 1 lb. per sq. in.

APPLIANCES

216. Combustion standards should be in accordance with *B.S.* 717–1936 (Addition 1940) or with any later specification, as far as the requirements apply.

217. Only appliances certified as satisfactory by approved " bottled " gas suppliers should be marketed, and all approved appliances should be so labelled.

LIGHTING EQUIPMENT

218. Ordinary taps are not ground sufficiently to prevent leakage, and lighting brackets must therefore be of special make. All lighting equipment for use with " bottled " gas should be stamped " Approved for ' bottled ' gas."

219. Lighting burners must be either full on or off. At a pressure below 10 in. w.g. sooting of mantles occurs.

VENTILATION

220. As the combustion of " bottled " gas for a given thermal output requires the same volume of air as does town gas, the arrangements made for the ventilation of appliances burning " bottled " gas should be similar to those made for appliances burning town gas.

GENERAL

221. The grease used on taps of town gas equipment becomes affected by " bottled " gas. All taps should be special fittings approved for " bottled " gas, and any grease used should be approved by the suppliers of the gas.

222. Where an appliance having a high gas rate, such as a bath water heater, is connected it is advisable to connect direct to a separate container of " bottled " gas. This will avoid a drop of pressure to other equipment in use at the same time.

223. The draw-off from one container should not exceed 16 cu. ft. per hour. Two or more containers can be connected in parallel for large consumptions.

224. Appliances with free burning flames should not be fitted in draughty positions owing to the instability of the flames.

APPENDIX C
TABLES

TABLE OF DISCHARGE FOR STRAIGHT HORIZONTAL PIPES WITH $\frac{1}{10}$-IN. DIFFERENTIAL PRESSURE FOR GAS OF DENSITY 0·50 RELATIVE TO AIR (CU. FT. PER HOUR)

NOTE. The figures given in this table are to be used as a basis in deciding the size of pipe to supply gas between the meter and various points of consumption on the premises. They refer to pipes of steam weight (British Standard) and are valid for gas of density from 0·4 to 0·5. When pipes of gas weight are used, the internal diameter of the pipe being larger the discharge is increased, and the values given are then applicable to gas of density greater than 0·5. It is to be noted that the tabulated figures refer to horizontal pipes. The effects of rising or falling pipes on the pressure head have not been taken into account.

SIZE OF PIPE IN INCHES (INTERNAL DIAMETER)	RELATIVE CARRYING CAPACITY	LENGTH OF PIPE IN FEET														
		10	20	30	40	50	60	70	80	90	100	125	150	175	200	250
$\frac{1}{8}$	1	$3\frac{1}{2}$														
$\frac{1}{4}$	7	25														
$\frac{3}{8}$	15	55	39													
$\frac{1}{2}$	29	108	76	62												
$\frac{3}{4}$	60	225	160	130	110	100	92									
1	127	470	330	270	235	210	190	175	165	155						
$1\frac{1}{4}$	250	930	655	535	465	415	380	350	330	310	295	260	240	220	205	185
$1\frac{1}{2}$	352	1,300	920	750	650	580	530	490	460	435	415	370	340	310	290	260
2	710	2,640	1,865	1,525	1,320	1,180	1,075	995	930	880	835	745	680	630	590	530
$2\frac{1}{2}$	1,360	5,055	3,575	2,920	2,525	2,260	2,065	1,910	1,785	1,685	1,600	1,430	1,305	1,210	1,130	1,010
3	2,210	8,240	5,830	4,760	4,120	3,685	3,365	3,115	2,915	2,750	2,605	2,330	2,130	1,970	1,840	1,650

TABLE GIVING ADDITIONS TO BE MADE TO OVERALL LENGTH OF A PIPE (IN FEET) FOR INCREASED RESISTANCE INTRODUCED BY FITTINGS

SIZE OF PIPE IN INCHES	ELBOWS	TEES	90° BENDS
$\frac{1}{2}$ to 1	2	2	1
$1\frac{1}{4}$ to $1\frac{1}{2}$	3	3	1
2	5	5	2
3	8	8	3

GLOSSARY

BAFFLER. A fitting inserted in a flue pipe, designed to divert down-draught and so prevent interference with combustion at the burner. (See *B.S.* 766, *Part I*, 1938.)

BEND. A piece of pipe curved to form the arc of a circle and by means of which the direction of the pipe line is altered. Bends may be $\frac{1}{32}$nd ($11\frac{1}{4}°$), $\frac{1}{16}$th ($22\frac{1}{2}°$), $\frac{1}{8}$th ($45°$), $\frac{1}{4}$ ($90°$).

" BOTTLED " GAS. Hydrocarbon gases, such as butane or propane, stored in portable containers and used as a substitute for town gas where the latter is not yet available.

BOX, SURFACE. See " Surface Box."

BY-PASS, METER. See " Meter By-pass."

" CALOR " GAS. A proprietary type of " bottled " gas.

CAP. A pipe fitting used to close or " cap " the end of a pipe. Fits over the end of the pipe. The end of a pipe so treated is termed a " capped " end.

CAPACITY (of a gas meter). The maximum rate, in cubic feet per hour, at which gas will pass through it within the permissible limits of pressure drop.

COCK. A device used to stop or regulate the flow of gas and operated by the rotation of a drilled or slotted plug.

COCK, STOP. See " Stop Cock."

CONCEALED CONNECTION. The method of connecting a gas fire or other gas appliance to the installation pipes so that no pipes or pipe fittings are visible.

CONDENSATE RECEIVER (SYPHON). A pot or box-shaped receptacle fitted at the lowest part of a gas pipe-line to collect any condensate which might form in the pipe. The condensate is pumped from the receiver through a stand-pipe (*q.v.*) connected to it.

CONNECTOR. A short piece of pipe about three times the length of a coupler (*q.v.*), fitted with two backnuts, and threaded (male) sufficiently to enable the couplers between which it is fitted to be run back over it and so allow of its removal.

CONNECTOR, GAS, PLUG AND SOCKET. See " Plug and Socket Gas Connector."

CONTROL. The cock or valve controlling the supply of gas from the undertaking to the consumer.

COUPLER. A cylindrical fitting pipe having female threads into which pipes may be screwed at either end and so be joined.

COVER. The depth from ground level to the top of a main or service pipe laid underground.

COVER, SURFACE BOX. See " Surface Box Cover."

DETACHABLE KEY. A handle or lever having at one end a square hole or shank for fitting over or into the spindle or a cock thereby enabling the plug to be rotated.

DRAUGHT DIVERTER. See " Baffler."

DUCT. Any channel or recess designed for the accommodation of pipes.

ELBOW. A pipe fitting by which the direction of the pipe line is altered at right angles but with less radius than that of a 90° bend (*q.v.*).

ELBOW, LONG SWEEP. See " Long Sweep Elbow."

ELBOW, SQUARE. See " Square Elbow."

FALL. The gradient at which a gas main or service pipe is laid and by means of which the proper drainage of any condensate is effected.

FITTING. See " Pipe Fitting."

FLOOR TRAP. A recess left in a floor and provided with a flush fitting cover to accommodate and provide access to a cock or pipe fitting or a concealed connection or pipe.

FLUE OUTLET. That part of a gas appliance which provides egress for the products of combustion and to which, if necessary, a flue pipe is connected.

GAS. Throughout this Report " Gas " is used to denote Town Gas as normally manufactured and distributed through the mains of an undertaking, as a public utility service.

GAS, " BOTTLED." See " Bottled Gas."

GAS, TOWN. See " Gas."

GAUGE. In reference to pipes : the thickness of the pipe wall.

GAUGE, PRESSURE. See " Pressure Gauge."

HOUSING, METER. See " Meter Compartment."

INDEX (of a meter). The series of dials or row of figures indicating the amount of gas passed through the meter.

IDENTITY PLATE. a. A metal plate affixed to an exterior wall or in some other visible position to indicate the location and purpose of a surface box (*q.v.*) or of a concealed cock or valve.

b. A small metal plate fitted on the surface of the wall of a room to indicate the location of a gas point.

INLET. The upstream or supply connection to a gas meter or appliance ; *e.g.* the gas service pipe connects to the inlet of a gas meter.

INSTALLATION PIPE. Every pipe between the control (*q.v.*) and the points at which the appliances are to be connected.

INTERNAL INSTALLATION. All gas equipment and accessories installed on the consumer's side of the control (*q.v.*).

KEY, DETACHABLE. See " Detachable Key."

LAGGING. Any material used for covering pipes or water tanks, either to minimise heat loss or prevent freezing.

LONG SWEEP ELBOW. An elbow offering less resistance to flow than an ordinary elbow.

MAIN. The undertaking's principal supply pipe in the public way and to which the service pipe is connected.

MAIN SUPPLY. Used in water-heating practice to mean a supply of water to an appliance taken direct from the water service pipe and thus under pressure from the main as distinct from a water supply taken from a cold-feed cistern.

METER. An apparatus for measuring directly or indirectly and indicating the volume of gas passing through it without interrupting the continuous flow of the gas.

METER BY-PASS. An arrangement of pipes and cocks or valves whereby the gas may be led round instead of through the meter. Used in schools, factories, hospitals and the like to ensure a continuous supply of gas should it be necessary to disconnect the meter.

METER, PRIMARY. See " Primary Meter."

METER, SECONDARY. See " Secondary Meter."

METER COMPARTMENT. a. A ventilated compartment of incombustible material provided as part of the structure of a building to accommodate the meter in a position accessible to the user and the undertaking.

b. In large premises, a specially constructed separate enclosure, room or out-building for the accommodation of the meter or meters.

METER UNION. A union (*q.v.*), one of two, on a gas meter, by means of which the pipes are connected. The service pipe connects to the inlet union and the installation pipe to the outlet union.

OUTLET. The downstream side or exit from a meter or appliance : *e.g.* the installation pipes connect to the outlet of the meter.

OUTLET, FLUE. See " Flue Outlet."

PIPE. Any conduit or tubular formation, and normally straight, used for the conveyance of a fluid (liquid or gaseous).

PIPE FITTING. Any coupler, connector, union, elbow, bend or tee-piece used in connection with a pipe.

PLATE, IDENTITY. See " Identity Plate."

PLUG. A pipe fitting used to close or " plug " the end of a pipe. Fits into the end of the pipe as distinct from a cap (*q.v.*) which fits over it.

PLUG AND SOCKET GAS CONNECTOR A standard bayonet-fitting plug, securely connected to a flexible pipe, and a socket permanently connected to a gas supply pipe to receive it, so arranged that the insertion of the plug opens the gasway and its withdrawal closes it. The socket may incorporate a gas regulating tap immediately behind it. Dimensions in accordance with *B.S.* 570–1934.

POINT. The termination of an installation pipe before the appliance is connected.

POINT, PRESSURE. See " Pressure Point."

PREPAYMENT METER. A meter (*q.v.*) fitted with a mechanism which, on the insertion of a coin or coins, permits the passage of the prepaid quantity of gas.

PRESSURE DROP (METER). The difference between the pressures on the inlet and outlet of a meter, representing the energy expended in operating the meter.

PRESSURE GAUGE. An instrument for indicating or recording the pressure of gas. Usually a " U " tube containing water.

PRESSURE POINT. A small plug-type pipe fitting on a service pipe, meter connection or installation pipe, to which a pressure gauge (*q.v.*) may be attached for taking a pressure reading.

PRIMARY METER. A meter (*q.v.*) connected to the service pipe and the index reading of which constitutes the basis of charge by the undertaking for gas used on premises where there may or may not be secondary or subsidiary meters (*q.v.*).

RECEIVER. See " Condensate Receiver."

SECONDARY METER. A subsidiary meter, the index reading of which is used as a basis of charge for gas between landlord and tenant or for indicating gas used in separate parts of premises the whole of which is supplied through a primary meter (*q.v.*)

SECTIONAL CONTROL A cock (or valve) used to control a section of a large installation.

SERVICE PIPE. The pipe between the undertaking's main and the control (*q.v.*).

SLEEVE. A tubular case inserted in a prepared hole in a structure for the reception of a service pipe, installation pipe or flue pipe.

SLIP SOCKET. A fitting used on a flue pipe to facilitate the connection and disconnection of the appliance to and from the flue.

SOCKET. The female end of a pipe into which the spigot of another pipe is inserted. Also used for a coupler (*q.v.*).

SPIGOT. The male end of a pipe which is inserted into the socket of another pipe.

SQUARE ELBOW. An elbow, the right-angled joint of which is mitred.

STAND-PIPE. A pipe taken from a condensate receiver (*q.v.*) to ground level and by means of which the condensate is removed from the receiver.

STOP COCK. A cock, usually of the screw-down type, used for controlling the flow of water in a water pipe or the supply of water to an appliance.

SURFACE BOX. A box, usually of cast iron, fitted at ground level with the top flush with the surface to provide access to a stand-pipe, valve, stop cock, etc.

SURFACE BOX COVER. The removable lid of a surface box (*q.v.*).

TAP. Gas : A cock (*q.v.*) when used at the point controlling a gas appliance. Water : A cock when used as a draw-off.

TEE. A pipe fitting which enables a branch pipe to be connected to another pipe at right angles. There is also a Y tee which enables a connection to be made at 45°.

TERMINAL. A fitting used at the termination of a flue pipe designed to minimise down-draught, to protect the open end of the flue from weather conditions and the entrance of substances which might restrict the free egress of the products of combustion.

TOWN GAS. See " Gas."

TRAP, FLOOR. See " Floor Trap."

TUBULAR. Any pipe fitting formed from pipe similar to that in connection with which it is used : *e.g.* a connector or bend, as distinct from a cast or stamped fitting.

UNION. A screwed-joint pipe fitting which facilitates connection and disconnection of pipes, pipe fittings and appliances.

VALVE. A device used to stop or regulate the flow of gas by the closure or partial closure of an orifice by means of a gate, flap or disc.

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1. To review existing information and practice concerning installations in buildings for :

   a. The supply of gas for all purposes from the point of entry of the gas to the property boundary to its delivery to an appliance ; and

   b. Gas-operated household appliances serving the single family dwelling.

2. To review proposals for improved gas-operated appliances for space heating, cooking, refrigeration, hot-water supply, and clothes washing and drying.

3. To make recommendations for practice in post-war buildings.

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21. SCHOOL BUILDINGS FOR SCOTLAND
By a Committee appointed by the Secretary of State for Scotland.

22. FARM BUILDINGS FOR SCOTLAND
By a Committee appointed by the Secretary of State for Scotland.

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POST-WAR BUILDING STUDIES

NO. 7

STEEL STRUCTURES

BY

A COMMITTEE CONVENED BY
THE INSTITUTION OF CIVIL ENGINEERS



LONDON: 1944
PUBLISHED FOR THE MINISTRY OF WORKS
BY HIS MAJESTY'S STATIONERY OFFICE
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A full list of the Reports which are being issued is given on the back page of the cover.

The Committees were either appointed by a Government Department or convened by a professional institution, a research association or a trade federation, as seemed most appropriate in each case; they were so constituted as to ensure that the Reports contain the considered views of experts and others closely concerned with the subject. The Minister gratefully acknowledges the work of the Committees and the valuable assistance given both by the various convening bodies and by the individual members. The Reports are not official publications in the sense that the Government as such is responsible for or necessarily accepts the views expressed, but their contents are authoritative and cannot but be of great value to all concerned with preparations for building after the war.

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INSTITUTION OF CIVIL ENGINEERS

THE STEEL STRUCTURES COMMITTEE

To the Right Honourable Lord Portal, D.S.O., M.V.O., Minister of Works.

MY LORD, We were convened in September 1942 by the Council of the Institution of Civil Engineers at your invitation. Our study was to be part of a scheme inaugurated by Lord Reith of Stonehaven, when Minister of Works and Building, with the object of securing a comprehensive and co-ordinated review of building technique for the guidance of those who would be responsible for the direction and organisation of building after the war.

We were charged with that part of the general scheme which relates to the construction of steel frameworks for buildings.

Our terms of reference were as follows:

> "To review the practice of steel-frame construction of buildings, and to make recommendations which will ensure in the post-war period the greatest practicable economies of material and the most rapid methods of construction, due regard being paid to interrelated requirements of modern buildings, such as lighting, ventilation, and plumbing."

The Ministry of Works suggested that the subject-matter should be considered under the following heads:

1. Intensity of loading on floors.
2. Application of methods of design based on true stresses in beam and columns instead of approximate methods now in general use.
3. Permissible stress intensities in steel members (stresses in compression flanges of beams partially restrained and in cantilevers).
4. Character of casing of steel members, and effect on strength and dead weight of structure.
5. Standardisation of construction with a view to reducing the number of types of rolled steel sections in common use.
6. Recommendations as to the extended use of welding in view of the great development of welding in the war period.
7. Recommendations regarding the designs of cleats and connections with a view to eliminating unnecessary work and materials.
8. Pressures on concrete foundations and types of support which reduce steel in column bases to a minimum.
9. Suggestions for elimination of customs in steel construction which may provide unnecessarily liberal margins of strength and are not dictated by the requirements of rational design.
10. The use of cold strip rolled light structural shapes for small span trusses, purlins, and subsidiary frames.

STEEL STRUCTURES

We considered the subject-matter given under the above heads in the course of five meetings, and also considered other matters which are included in this Report under the heading of Additional Comments.

We appointed a Sub-Committee consisting of Mr. B. L. Hurst, Professor J. F. Baker, and Mr. C. Hipwell, to meet three representatives of the Reinforced Concrete Structures Committee (Dr. Oscar Faber, Mr. W. C. Andrews, and Mr. Leslie Turner), to consider the question of loads and stresses in connection with the above-named heads (1) and (3). The Joint Sub-Committee's recommendations were adopted by us and are embodied in this Report.

ABBREVIATIONS

D.S.I.R. Department of Scientific and Industrial Research.
B.S.I. British Standard Institution.
B.S. British Standard.

STEEL STRUCTURES

A REPORT BY A COMMITTEE CONVENED BY THE INSTITUTION OF CIVIL ENGINEERS

RECOMMENDATIONS, COMMENTS, AND SUGGESTIONS

The following are our recommendations, comments, and suggestions under heads 1 to 11:

1. INTENSITY OF LOADING ON FLOORS

We recommend:

i. That, for loads on public floors, dance halls, etc., the D.S.I.R. and *B.S.* 449-1937 figures be accepted.

ii. That a footnote be added after the paragraph dealing with the minimum total allowance for internal partitions warning engineers or designers that the rate of 20 lb. per sq. ft. of floor area will not always be adequate.

iii. That investigations be made with a view to formulating rules for the permissible weight of partitions (of variable position) in relation to methods of floor construction.

iv. That partitions, which are now treated as dead load and not as superimposed load, should in future be treated as superimposed load rather than as dead load.

v. That, with regard to wind loads, paragraph 4 of the *Report on Steelwork for Buildings*, Part I, "Loads and Stresses," published by the Institution of Structural Engineers, be accepted, with the exception of paragraph (*c*), where the L.C.C. by-laws should be retained for the wind loads on sloping roofs.

2. APPLICATION OF METHODS OF DESIGN BASED ON TRUE STRESSES IN BEAMS AND COLUMNS instead of Approximate Methods now in General Use.

We recommend:

i. That insufficient experience has been obtained to justify any deviation from the recommendations of the revised Code of Practice prepared by the Joint Committee of Civil and Structural Engineers based upon the accurate methods of stress analysis given in the Final Report of the Steel Structures Research Committee, 1936.

ii. That, in order to obtain further and continuing experience, when buildings are to be designed or sponsored by government departments, the designs be based upon more exact design methods developed in the Final Report of the Steel Structures Research Committee, 1936, relating to the load-carrying capacity of the structure rather than limiting working stresses, and that the designs and calculations for these buildings be published so as to form a possible basis for the drafting of improved empirical methods, which may well prove to be more economical.

3. PERMISSIBLE STRESS INTENSITIES IN STEEL MEMBERS (Stresses in Compression Flanges of Beams Partially Restrained and in Cantilevers).

We recommend for structural steel:

i. That the working stresses in *B.S.* 449–1937 for mild steel and for high-tensile steel be retained, but that the increased stresses recommended as a War Emergency Revision (yellow insertion, dated May 1940) be retained for industrial buildings, and single-storey buildings only, except the revision to Clause 18.

ii. That, for the purpose of this clause, industrial buildings shall include those which are scheduled in Classes 5 and 6 of Clause 4 of the L.C.C. by-laws, and also heavier buildings designed for similar purposes.

iii. That Clause 18, "Stresses due to Wind Forces," of *B.S.* 449–1937 be adopted, but that the words "In no case shall the maximum stress exceed $10\frac{2}{3}$ tons per sq. in. for mild steel, or 16 tons per sq. in. for high-tensile steel," be added to this clause.

iv. That, for high-tensile steel complying with *B.S.* 548–1934, a corresponding increase in general may be permitted in industrial and single-storey buildings, but that the details require further consideration.

We recommend for reinforced concrete:

v. That no war-emergency increases shall apply, and that the stresses shall never exceed 25,000 lb. per sq. in., or half the guaranteed yield point, whichever is less, and in mild steel, *B.S.* 15–1936, for which there is no guaranteed yield point, the present L.C.C. stresses be adhered to. (If *B.S.* 15 1936 is revised so as to require a minimum yield point, the stresses in mild steel might be reconsidered.)

4. CHARACTER OF CASING OF STEEL MEMBERS, and Effect on Strength and Dead Weight of Structure.

With regard to the encasement of beams, we recommend:

That, where encasements comply with Clause 13 of B.S. 449–1937, the additional stresses therein specified may be worked to; similarly, in the War Emergency Revision of this specification, the additional stresses for concrete encasement specified therein, may also be worked to in the case of industrial buildings or single-storey buildings.

With regard to the encasement of columns, we noted from information furnished by the D.S.I.R. and Fire Offices' Joint Committee on Fire Grading, that tests carried out to date upon the strength of gravel concrete under conditions of high temperature appear to show:

That, when ballast concrete is heated to a temperature of 400° C., the reduction in its compressional strength becomes appreciable.

That ballast concrete surrounding a steel stanchion reaches this temperature at a depth of 2 in. after a two-hour fire test conforming with *B.S.* 476–1932, and at a probable depth of about 6 in. after a four-hour test.

In view of the above figures, we decided that the information at present available is inadequate to permit adoption of any increased stresses for encased stanchions, but we suggest that further tests are necessary and noted the following types of encasement as being suitable for test:

i. *In situ* ballast concrete (further tests if considered necessary).

ii. *In situ* brick concrete.

iii. *In situ* concrete with various stone aggregates.

iv. Two-inch thick brick blocks with brick concrete filling.

The effect on the above casings of surface treatment such as asbestos spray should be investigated at the same time.

We have met representatives of the Building Research Station and agreed a programme based upon the above suggestions.

5. STANDARDISATION OF CONSTRUCTION with a view to reducing the number of types of Rolled Steel Sections in common use.

We were of the opinion that the merits of broad flange beams should be considered as, in many cases, they will effect considerable economy. Apart from these, we decided against any variations in the existing number of sections.

6. RECOMMENDATIONS AS TO THE EXTENDED USE OF WELDING in view of the Great Development of Welding in the War Period.

We recommend:

i. That, subject to rules to safeguard the quality of welding, its use should be encouraged in all suitable cases.

ii. That the utmost use should be made of welding in the shops or on the ground, but when the steel is in position welding should only supersede bolt connections where economy of material or labour would result.

iii. That, where welded site connections are made, due allowance should be made for rigidity given to them at the joints.

iv. That the degree of strength to be provided in temporarily bolted connections which secure the structure until the site welding is effected, requires consideration in the case of multi-storey construction.

v. That, having regard to the report issued in 1938 by the Steel Structures Research Committee on the welding of structural steelwork, and to the regulations made in 1937 and 1939 by the L.C.C. relating to applications for waivers of building by-laws to permit of the use of electric metal arc and oxy-acetylene welding instead of riveting, bolting or lapping, typical details of various types of joints and connections be prepared, together with tables giving safe loads on various types of connection.

vi. That encouragement should be given to the development of new types of design which the special character of welding makes possible.

7. RECOMMENDATIONS REGARDING THE DESIGNS OF CLEATS AND CONNECTIONS with a view to Eliminating Unnecessary Work and Materials.

We recommend:

i. That girder cleats to stanchions should generally accord with the recommendations of the Code of Practice published jointly by the Institutions of Civil and Structural Engineers.

ii. That no splay cuts or other similar refinements be called for on cleats or connections, unless necessary for a skew connection or for the purpose of equalising stress distribution.

(See Recommendation No. 6 in regard to details of welded connections.)

8. PRESSURES ON CONCRETE FOUNDATIONS and Types of Support which reduce Steel in Column Bases to a Minimum.

We are of the opinion that the pressures given on p. 36 of *B.S.* 449-1937 appear to be reasonable. These pressures will often make the use of bloom bases more economical than riveted bases. Bloom bases should be calculated on the basis given in *B.S.* 449 1937.

9. SUGGESTIONS FOR ELIMINATION OF CUSTOMS IN STEEL CONSTRUCTION which may Provide Unnecessarily Liberal Margins of Strength and are not Dictated by the Requirements of Rational Design.

We agreed:

i. That the specification of "square necks" for foundation bolts is inadvisable; and that, in view of the fact that unnecessary foundation bolts are frequently specified, the question of their need should be investigated in all cases.

ii. That variation in widths and thicknesses for slab bases be reduced to the practical minimum. That standard widths and thicknesses of slabs be tabled in section books and that the B.S.I. be requested to consider the question of preparing a standard in this connection.

That in the case of a slab base bearing on concrete, machining of the under side and edges is unnecessary.

iii. That, in the case of built-up bases bedded on concrete and solidly grouted or filled underneath with fine concrete, there is no need to countersink and flush chip the under side rivet heads.

iv. That, where a stanchion end or joint has been machined for a dead bearing, the rivets connecting the base, cap or joint to the stanchion shall only be those necessary to take the bending moment and to furnish a good connection.

v. That, in plate girder construction, the depth over flange angles be greater than the nominal depth of the web plate so that the edge planing of webs is eliminated.

That lines 28 to 40, Clauses 23 (f) of *B.S.* 449–1937 be deleted.

That, as the staggering of joints in plate girder flange angles involves additional cost, the necessity for such staggering be considered for each particular case.

That, where stiffeners are riveted or welded to the web of a plate girder or beam, close fitting of their ends to flanges should not be insisted upon except where necessary over bearings, under concentrated loads or where the flanges need support.

That, as camber in plate girders adds to the cost, this be avoided except where essential.

That joints in the compression flanges of a girder must be fully covered unless the abutting ends have a machined dead butt, in which case the cover need be adequate only to maintain the parts in position and resist all secondary stresses.

vi. That "smithed" work such as joggled flanges of joists and other beams should be avoided.

That joggled stiffeners should generally be avoided.

vii. That, as welding affords a ready means of constructing stair stringers, mansard frames, etc., this be used in lieu of bent plates, etc., at the mitre.

viii. That, when expressions such as "cut dead" and "cut exact" are applied to the length of members, such expressions should always be accompanied by a statement of the limits of tolerance required. If not, the standard limits shall apply, *i.e.* $\frac{1}{8}$ in. over, $\frac{1}{8}$ in. under.

That, where the end of a beam is provided with web cleats to transmit the load, such cleats shall be permitted to project $\frac{1}{8}$ in.

That, where a beam is carried by a bracket fixed to the supporting member, an end clearance of $\frac{1}{8}$ in. shall be permitted.

ix. That a "notched" end should imply notched sufficiently only to clear. If "notched to fit" is intended, this should be specially described, but in general this requirement should be avoided.

That machine gas-jet cutting be accepted subject to the tolerances mentioned above. Hand tools may be used for notches and other similar locations, subject to a smooth finish.

x. That the standard list of symbols of the Institution of Structural Engineers be adopted for use in the design of structural steelwork.

10. THE USE OF COLD STRIP ROLLED LIGHT STRUCTURAL SHAPES for Small Span Trusses, Purlins, and Subsidiary Frames.

We consider that considerable economy would be achieved by the proper use of cold steel strip rolled light structural shapes, provided that safeguards are obtained against corrosion and fire risk.

We suggest that this matter be dealt with now by an authoritative committee in order that the results may be available.

11. ADDITIONAL COMMENTS

We wish to point out that, apart entirely from the question of structural design, there are other aspects of the handling of contracts for steel building frame work.

Economy in time and money would be effected by:

The supply of full information with the placing of the contract.

The avoidance of revisions (even of a minor nature) after the commencement of fabrication.

The early checking and return with comments of detail drawings, etc.

The provision of an adequate survey before the building is designed.

The provision of a time schedule covering the client, the professional advisers, and the contractors, so as to correlate all sections of the work from the date of letting the contract to its completion.

We recommend:

That a standard basic form of specification covering such matters as are referred to above be prepared.

DAVID ANDERSON,
Chairman.

22 *October*, 1943.

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STEEL STRUCTURES COMMITTEE

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Co-opted Members

A. Ramsay Moon, B.A., B.Sc., M.I.Struct.E., Director of Research of the Institute of Welding.
J. F. Farquharson, M.I.Struct.E., Representative of the Ministry of Works.

Joint Sub-Committee of Committees on Steel Structures and on Reinforced Concrete Structures:

B. L. Hurst Professor J. F. Baker C. Hipwell	Representing the Steel Structures Committee.
Dr. Oscar Faber W. C. Andrews Leslie Turner	Representing the Reinforced Concrete Structures Committee.

The Committee wish to record the loss which they suffered on the death of Mr. B. L. Hurst.

TERMS OF REFERENCE

To review the practice of steel frame construction and building, and to make recommendations which will ensure in the post-war period the greatest practicable economies of material and the most rapid methods of construction, due regard being paid to interrelated requirements of modern buildings, such as ventilation, and plumbing.

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By a Committee convened by the Royal Institute of British Architects.

16. BUSINESS BUILDINGS
By a Committee convened by the Royal Institute of British Architects.

The following are in course of preparation:

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22. FARM BUILDINGS FOR SCOTLAND
By a Committee appointed by the Secretary of State for Scotland.

HIS MAJESTY'S STATIONERY OFFICE

S.O. Code No. 70-441-7

POST-WAR BUILDING STUDIES

NO. 8

REINFORCED CONCRETE STRUCTURES

BY

A COMMITTEE CONVENED BY
THE INSTITUTION OF STRUCTURAL ENGINEERS



LONDON: 1944
PUBLISHED FOR THE MINISTRY OF WORKS
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INSTITUTION OF STRUCTURAL ENGINEERS

THE REINFORCED CONCRETE STRUCTURES COMMITTEE

To the Right Honourable Lord Portal, d.s.o., m.v.o.,
Minister of Works.

MY LORD, We were convened in September 1942 by the Institution of Structural Engineers at your invitation. Our study was to be part of a scheme inaugurated by Lord Reith of Stonehaven, when Minister of Works and Building, with the object of securing a comprehensive and co-ordinated review of building technique for the guidance of those who would be responsible for the direction and organisation of building after the war.

We were charged with that part of the general scheme which relates to reinforced concrete. Our terms of reference within this study of building were as follows:

> "To review the practice of reinforced concrete construction of buildings, and to make recommendations which will ensure in the *post-war period* the greatest practicable economies of material and the most rapid methods of construction, due regard being paid to the interrelated requirements of modern building, such as lighting, ventilation, plumbing, etc."

Your Committee held its first meeting on the 10th September, 1942, since when it has held twelve meetings, up to and including 14th October, 1943.

The Committee has not dealt with the question of fire protection to reinforced concrete structures, nor given consideration to A.R.P. matters.

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ABBREVIATIONS

D.S.I.R. Department of Scientific and Industrial Research.
B.S. British Standard.
B.I.N.C. Building Industries National Council.

REINFORCED CONCRETE STRUCTURES

A REPORT BY A COMMITTEE CONVENED BY THE INSTITUTION OF STRUCTURAL ENGINEERS

1. CONSIDERATION OF CODE OF PRACTICE

The Committee recommends that a new Code of Practice for reinforced concrete should be prepared, preferably administered on a national basis, that this code should contain a power of waiver, and that any waivers granted shall be published. It also recommends that the code be revised every three years, that any published waivers be incorporated in so far as they may apply generally, and that the code be made applicable throughout the United Kingdom.

In view of the waste of time and confusion often caused by designers using different symbols for the same quantities, it is recommended that the Institution of Structural Engineers' Schedule of Symbols should be adopted in the code, and that engineers should be urged to use such symbols in their calculations. Lists of these symbols are given in the Appendices.

2. LOADS ON FLOORS AND ROOFS

The Committee appreciated that if it had been able to reduce the loads for which floors are specified to be designed some economy in construction would result. The Committee, therefore, gave very careful consideration to the existing floor loads with this end in view, and it formed the opinion that the loads had been drastically reduced only a few years ago and the stresses simultaneously raised, and that the case for still further reducing loads would have to depend on a very extensive scientific investigation, results of which were not before the Committee. Furthermore, the Committee had carefully in mind the fact that during actual building construction accidental loads, such as storage of building materials on floors, inevitably take place, and that floors which would not carry reasonable loads of this character would be inconvenient and tend to increase the time of building by requiring additional temporary strutting or other precautions. Nevertheless these considerations were not thought to apply so strongly to domestic dwellings of two storeys or under.

Eventually it was decided to recommend:

a. That, for loads on public floors, dance halls, etc., the D.S.I.R. and *B.S.* 449–1937 figures be accepted.

b. That a footnote be added after the paragraph dealing with the minimum total allowance for internal partitions, warning engineers and designers that the rate of 20 lb. per sq. ft. of floor area will not always be adequate.

c. That the above allowance for partitions, which is now treated as dead load, should in future be treated as superimposed and not as dead load.

d. That, with regard to wind loads, Clause 4 of the *Report on Steelwork for Buildings*, Part I, "Loads and Stresses," published by the Institution of Structural Engineers, be accepted, with the exception of sub-section (*c*). L.C.C. by-laws should be retained for wind loads on sloping roofs.

That in domestic buildings of not more than two storeys:

a. The superimposed floor load may be taken as 40 lb. per sq. ft. on slabs and 30 lb. per sq. ft. on beams, with no alternative loading.

b. Roofs having a slope not exceeding 20° to the horizontal may be designed for a superimposed load of 30 lb. per sq. ft. on slabs and 25 lb. per sq. ft. on beams.

Though this only gives relief from existing loads in the case of domestic buildings, it is felt that the number of buildings affected will be so great that the change will represent a very substantial saving in the cost of national rebuilding.

3. STRESSES IN STEEL AND CONCRETE

The Committee appreciates to the full the importance of achieving economy in design with a view to saving labour and materials in construction, and it is pleased to be able to recommend that the stresses in concrete in compression due to bending shall be raised by 10 per cent. from those given in Tables III and IV of the B.I.N.C. Code of Practice. It does not, however, recommend that any of the other concrete stresses shall be modified.

With regard to steel reinforcement, the Committee feels that a small increase in steel stresses makes only a very small difference in the cost of a building or structure, and that increased stresses in steel reinforcements in reinforced concrete have to be limited by two considerations:

a. The yield-point of the material.

b. The production of cracks in the concrete which would be damaging to the permanence and general usefulness of the structure.

With regard to (a) the Committee deems it unfortunate that the British Standard for Mild Steel contains no requirements as to a minimum yield-point, and it feels that this is a weakness in the British Standard which should be remedied if at all possible. Until such a yield-point stress finds its place in the B.S. the Committee recommends that no increase in the present stress of 18,000 lb. per sq. in. in tension be adopted.

In the case of steels in which the strength and the yield-point have been increased beyond that of mild steel, either by varying the chemical composition or by cold working, the Committee recommends that the working stress may be taken as half of the guaranteed and tested yield-point, subject, however, to a proviso that in no circumstances shall the stress ever exceed ceiling stresses of 25,000 lb. per sq. in. for beams and 27,000 lb. per sq. in. for slabs. The last proviso shall not apply to pre-stressed reinforced concrete.

If *B.S.* 785–1938 is revised so as to give a minimum yield-point requirement, then the Committee would be willing to reconsider the stresses in mild steel. The Committee recommends that the British Standards Institution be asked to consider specifying such a minimum yield-point in the case of mild steel reinforcement.

With regard to increased stresses being allowed when dealing with wind forces, the Committee recommends that the permissible stresses given in Clauses 13 and 14 respectively of the B.I.N.C. Code may be exceeded by not more than 33⅓ per cent. for the reinforcement and 20 per cent. for the concrete stresses, provided:

a. That such excess is solely due to stresses induced by wind loading.

b. That they shall not apply to stresses in roof construction above the topmost floor level in a building.

c. That in no case shall the ceiling stresses previously referred to be exceeded.

The Committee recommends that for water-retaining structures the Institution of Structural Engineers' report on this subject be adopted.

4. IMPROVEMENT IN DESIGN AND CONSTRUCTION METHODS

The Committee's opinion is that the best and most direct way of achieving improvement in design and construction methods is to insist that only properly qualified persons should be entrusted with the design of reinforced concrete. If this is done it feels that the 10 per cent. increase in working stresses in concrete which has been recommended above can safely be advocated, though it would have hesitated to make such a recommendation unless it were coupled with the present proviso with regard to the limiting of design to qualified persons.

Apart from this the Committee feels that the designer should be allowed an open field for the exercise of his ingenuity, and, provided the Code of Practice recommended is adopted, this, in the opinion of the Committee, gives the engineer all the scope he requires. A further increase in working stresses could only, in the view of the Committee, be justified when materials and a high uniform standard of workmanship can be relied upon.

With a view to ensuring a higher standard of workmanship the Committee recommends:

a. That only experienced reinforced concrete contractors should be employed on reinforced concrete work.

b. That operatives engaged in the mixing and laying of concrete, under the supervision of clerks of works, inspectors, etc., should be trained as craftsmen and be known as "concretors."

c. That the work of steel fixing and bending should be considered as a definite trade and be recognised as such by the trade unions.

d. That suitable training should be given to operatives engaged on the erection of formwork, which should also be considered as a special trade recognised by the trade unions.

e. That persons supervising reinforced concrete construction, such as clerks of works, inspectors, or resident engineers, should receive a suitable training and be certificated, as well as those in charge of reinforced concrete construction on the site on the contractor's behalf.

In the past a great deal of time has been taken in supplying calculations to the local or other authorities and waiting until these have been checked by a person not always more competent or experienced than the engineer responsible for the design. It is felt that a great deal of time could be saved by requiring that, where work is designed by qualified chartered structural or civil engineers, there shall be no need to submit calculations, provided the qualified designing engineer has furnished to the local or other authority a certificate that the work complies with the Code of Practice for Reinforced Concrete.

Detailed recommendations on matters which would result in economy or saving of time would include the following:

a. Hooks or other forms of anchorage at the ends of all rods should not be insisted upon where they are unnecessary.

b. Passage of all pipes, ducts, heating, ventilating, etc. should, wherever possible, be indicated on plans available before final reinforced concrete details are prepared and actual construction commenced, so that provision for these could be made and wasteful cutting avoided.

c. The designing engineer should be consulted at the earliest stage of planning, so as to secure the utmost economy of construction.

d. Specifications should call for concretes of given strengths and impermeability, and the volumetric proportions shown in Tables III and IV of the B.I.N.C. Code of Practice may be varied at the discretion of the engineer.

e. A standard arrangement of specification for reinforced concrete should be laid down.

f. Formwork or shuttering should be designed and not left to the foreman on the job.

g. Permanent shuttering should receive careful consideration; for external work such materials as brick and reconstructed facing stone, and for interior work such materials as breeze blocks, insulation boards, etc. may deserve consideration.

h. A special report should be prepared giving guidance to contractors on reinforced concrete work carried out in cold weather.

j. Designers should give special consideration to the use of central mixing plants for concrete and special methods of transporting concrete to the sites.

k. Recommendations should be drawn up for simple finishings to exposed concrete surfaces.

m. Much reinforced concrete has been damaged through inadequate cover of concrete over the reinforcement, and it is recommended that for external work not otherwise protected the cover of concrete shall be increased by half an inch above the present requirements.

n. The Committee discussed at some length the standardisation of concrete sections and floor slabs, and came to the conclusion that standardisation of sections is in general undesirable, but that multiplicity of sections in any one building should be avoided.

5. LOAN PERIODS

It is felt that reinforced concrete has now long passed the experimental stage and that where the precautions referred to in this Report and in the Code herein recommended are adopted, there is no longer any justification for the authorities granting shorter loan periods for reinforced concrete than for other forms of construction. The fact that shorter loan periods have in the past been insisted upon has in many cases militated against the use of the most suitable and economical material and this, at any rate from now onward, would be against the national interest.

6. REINFORCED CONCRETE FOUNDATIONS

The design of reinforced concrete foundations should be entrusted only to persons specially qualified in this class of work. Such design should be based on a careful investigation of the actual bearing capacity of the soil, which should be made in advance of the structural design, and this course would tend to economy as against the acceptance of rule of thumb methods and the adoption of arbitrary safe pressures on soil materials. It is felt that there has probably been more wasteful design in connexion with foundations than with other portions of structures. It is recommended that before a foundation is designed the relative merits of many different types should be carefully examined, for example, piling, piers, rafts, etc. This examination requires a knowledge of soil mechanics and a study of the particular soil strata in question as well as the condition and configuration of

adjacent buildings, etc., and can only be carried out by a person having particular knowledge and experience. The Committee is satisfied that considerable economies which can be achieved by more careful design of foundations.

In particular it is the view of the Committee that reinforced concrete foundations are generally more economical than:

a. Steel grillages encased in concrete.

b. Brick footings with mass concrete under.

Some foundations have been rendered expensive by the legal necessity of keeping the foundations within the boundaries of the site, whereby some type of cantilever foundation becomes necessary. In London there is legislation providing for spreading foundations over a neighbour's soil, subject to suitable notices, etc., and economy would be effected in foundation design if similar provision were made legal throughout the country.

Attention is drawn to the Institution of Structural Engineers' report on *Foundations in Disturbed Ground.*

In the case of domestic houses without basements it is sometimes found that laying a reinforced concrete raft over the whole site and so avoiding any excavation other than the removal of top soil leads to considerable economy. The raft acts as a ground floor, and has sufficient spreading power to enable brick footings to be omitted. Each case requires the consideration of a specially qualified person, and such constructions have often been found economical on extremely bad soils, and are worthy of consideration even on good soils with a view to achieving speed and economy.

7. PRE-STRESSED AND VIBRATED CONCRETE

It is recommended that the use of pre-stressed concrete should be permitted under suitable safeguards, and that any new Code should be extended to provide for this when there is sufficient experimental and practical experience on the subject.

Attention is drawn to the fact that most methods of pre-stressing are the subject of patents.

Encouragement should be given to the use of vibrated concrete with low water/cement ratio, with a view to increased strength and consequent reduction in cost.

The exact method of vibration must be specified in detail by the engineers.

8. WELDING

Welding by gas or electricity has now reached such a stage of development that it should be permitted under suitable conditions and with suitable safeguards.

Welding is of two kinds:

a. Tack or positional welding between rods crossing more or less at right angles so as to fix them in position.

b. Butt welding between the ends of rods in line whereby stress is transferred across the section.

In the case of (a) no special precautions in regard to stress are needed.

In the case of (b) it is recommended that this should only, at present, be allowed for mild steel. In the case of rods of mild steel which have their strength increased by cold working butt welding may be permitted, but the stress at the weld should be limited to that appropriate to mild steel, and the additional strength obtained by cold working should be ignored at and near the weld.

9. COMPOSITE CONSTRUCTION

The Committee feels that there are many cases where an economical and rapid form of construction may consist of a light structural steel frame, subsequently cased with concrete and may-be additionally reinforced. Such structure may be designed to carry its temporary loads as a skeleton framework and the composite structure designed to carry the permanent loads. The Committee recommends that the basis for such design shall be that appropriate to composite materials, the steel and concrete acting together with their appropriate modular ratio.

A Code to deal with this construction could be embodied in the Code of Practice if it were thought desirable.

10. CODE OF PRACTICE

Though the Committee appreciates that it was not asked to prepare a new Code of Practice for Reinforced Concrete it felt, nevertheless, that it was unable to give detailed recommendations sufficiently clearly without considering the present Codes clause by clause and giving its recommendations thereon. It has therefore done this, and has gone through the existing Codes in detail, selecting the best clauses from all those available, and in some cases modifying them so as to give effect to what it considers to be the best and latest practice.

As a result of this study it recommends that the existing Code of Practice for the Use of Reinforced Concrete in the Construction of Buildings, based on the D.S.I.R. recommendations adopted as by-laws by the L.C.C. and amended by the Building Industries National Council, should form the basis of the new Code of Practice. In addition to giving effect to all the foregoing recommendations the Code should be subject to the following modifications, which relate to the B.I.N.C. Code:

CLAUSE 2: DEFINITIONS. The definition for "reinforced concrete" to be altered to read: "'Reinforced concrete' is concrete which depends for its strength and/or stability on its reinforcement."

CLAUSE 8: CEMENT. The last paragraph of this clause, "Wherever cement is used it shall not be moved or disturbed after one hour from the time it has come into contact with water until it has set hard," to be deleted.

CLAUSE 10: CONCRETE. The first sentence of this clause, "Concrete shall consist of aggregate mixed with cement," to be deleted.

CLAUSE 13: PERMISSIBLE STRESSES IN CONCRETE. In Tables III and IV the stresses in compression due to bending to be raised by 10 per cent.

CLAUSE 14: PERMISSIBLE STRESSES IN REINFORCEMENT. *B.S.* 785–1938 to be referred to in place of *B.S.* 15–1936. The following words to be added at the end of sub-section (*c*): "That in no case shall the permissible stress in compression reinforcement exceed 18,000 lb. per sq. in. for mild steel and 20,000 lb. per sq. in. for any other steel."

CLAUSE 15: STRESSES DUE TO WIND FORCES. The words "for the reinforcement and 20 per cent. on the concrete stresses," to be included after "33⅓ per cent.," and the following to be added at the end of the clause: "Notwithstanding anything in the above clause, the ceiling stresses previously referred to shall not be exceeded."

CLAUSE 16: FABRICATION. This clause to be deleted and the following substituted:

"TESTING. Loading tests on a completed structure or structural member may be demanded in all cases where there is reasonable doubt as to the adequacy of the strength of any part of the structure."

CLAUSE 17: This clause to be deleted and the following substituted:

"Computation of stresses should accord with the laws of mechanics and the recognised general principles relating to the design of reinforced concrete."

CLAUSE 19: COVER. The following to be included: "That for external work the cover of the concrete shall be increased by half an inch."

CLAUSE 23: That for reinforced concrete floors containing hollow tiles, the recommendations contained in the *Report on Reinforced Concrete for Buildings and Structures*, Part IV, "Design and Construction of Hollow Floors," published by the Institution of Structural Engineers, be adopted.

CLAUSE 24: BENDING MOMENTS. The first five lines of sub-section (*b*) to be deleted, down to "bending moments in beams. . . ."

CLAUSE 26: BOND AND ANCHORAGE. The words "provided the average bond stress does not exceed the permissible," to be added at the end of the first paragraph of sub-section (*c*); this to be followed by "At any section in a beam the total adhesion on the side furthest from the point of maximum moment, being the sum of the rods at the permissible bond stress plus the value of anchorage, shall be at least equal to the tension at the section."

CLAUSE 27: GENERAL CLAUSES. The words "each of" to be added after "necessary restraint against buckling of" in the third line of sub-section (*b*) (i); the words "except in columns less than twelve inches by twelve inches where it may be three-sixteenths of an inch," to be added at the end of the second paragraph of the same sub-section; and the words "Every bar in a column shall be properly linked," to be added at the end of the clause.

CLAUSE 28: PERMISSIBLE LOADS. The words "0·75 of the distance from floor level to floor level" (right-hand column, fourth section, of the table) to be deleted, and the following substituted: "0·75 of the length between adequate lateral restraints."

CLAUSE 42: WALLS. The Committee recommends that careful consideration should be given to wall thicknesses required for domestic dwellings of not more than two storeys, and it feels that considerable relaxation could be allowed as regards the requirement of 4 inches for external walls and 8 inches for party walls, but as these probably require to be considered also by the Committee for Fire Grading of Buildings it hesitates to submit any specific figures at this stage.

OSCAR FABER,
Chairman.

14*th October*, 1943.

APPENDIX A

SCHEDULE OF SYMBOLS RECOMMENDED FOR USE IN REINFORCED CONCRETE CALCULATIONS

A	Area in general (in particular area of concrete in compression).
A_b	Equivalent area of spiral reinforcement (vol. of spiral per unit length of column).
A_c	Area of steel in compression.
A_k	Area of concrete in column core.
A_t	Area of steel in tension.
A_w	Area of web or shear reinforcement.
a	Lever arm or distance between centroids of forces producing the resistance moment.
a_1	Lever arm ratio $=\frac{a}{d}$.
B	Overall breadth of concrete section.
b	Breadth or width of tee or ell in beam with slab.
b_r	Breadth or width of rib of beam.
C	Total compressive force on section.
c	Stress in concrete in compression.
c_t	Stress in concrete in tension.
D	Diameter in general (in particular of column head supporting flat slab, overall concrete depth ; least lateral dimension of column).
d	Effective depth.
d_c	Inset of compression steel.
d_s	Total depth of slab or flange.
Δ or δ	Deflection.
E_c	Modulus of elasticity of concrete.
E_s	Modulus of elasticity of steel.
e	Eccentricity.
F.S.	Factor of safety.
I	Moment of inertia (suffixes as required).
K	Coefficient in general.
K_b	Stiffness of beam.
K_l	Stiffness of lower column.
K_u	Stiffness of upper column.
k	Radius of gyration.
L	Length in general (in particular, or actual column height or centres of columns in flat slabs).
L.F.	Load factor.
l	Effective span of beam or slab or effective height of column.
M	Bending moment (suffixes as required).
MR	Moment of resistance of section to bending.
m	Modular ratio $=\frac{E_s}{E_c}$.
n	Neutral axis depth.
n_1	Neutral axis depth ratio $=\frac{n}{d}$.
O	Sum of perimeters of reinforcement.
O.W.	Own or self weight of member.
p	Pitch.
Q	Coefficient in $MR = Qbd^2$.

R Reaction (suffixes as required).

r Steel ratio $=\frac{A_t}{bd}$ for tensile reinforcement.

r_1 Steel ratio $=\frac{A_c}{bd}$ for compression reinforcement.

S Shear force.

s Shear stress.

T Total tension or tensile force on section.

t Tensile stress in reinforcement.

t_b Stress in spiral or helical binding reinforcement.

t_w Stress in web or shear reinforcement.

u Ultimate concrete stress = cube crushing strength.

W Total load on beam or slab.

w Total load per unit area of slab or length of beam.

w_d Dead load per unit area.

w_l Live load per unit area.

Z Section modulus (suffixes as required).

z_x, z_y Bending moment coefficients for two-way rectangular slabs.

APPENDIX B

SCHEDULE OF SYMBOLS RECOMMENDED FOR USE IN STRUCTURAL STEELWORK CALCULATIONS

A Area in general (in particular area of section in square feet).

a Area of section in square inches.

B Breadth in feet.

b Breadth in inches.

D Depth in feet.

d Depth in inches.

E Modulus of elasticity of steel.

e Lever arm of eccentricity.

F Permissible unit stress (generally).

F_a Permissible axial compressive stress.

F_b Permissible flexural stress.

F_c Permissible combined stress.

F_s Permissible shear stress.

F_t Permissible axial tensile stress.

f Actual unit stress (generally).

f_a Actual axial compressive stress.

f_b Actual flexural stress.

f_c Actual combined stress.

f_s Actual shear stress.

f_t Actual axial tensile stress.

I Moment of inertia.

K Coefficient in general.

K_b Stiffness of beam $\frac{I}{l}$.

K_l Stiffness of lower column.

K_u Stiffness of upper column.

k Radius of gyration.

$\frac{l}{k}$ Ratio of slenderness.

L	Effective length in feet.
l	Effective length in inches.
L_a	Actual length in feet.
l_a	Actual length in inches.
M	Bending moment.
MR	Moment of resistance.
ow	Own weight.
owc	Own weight and casing.
R	Resultant force.
$R_L R_R$	Reactions.
W	Total load.
w	Unit load.
Z	Section modulus.
Δ or δ	Deflection.

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Mr. C. Lovett Gill, F.R.I.B.A., and Mr. H. R. Cox, M.I.Struct.E., were originally appointed to the Committee, but later, to the regret of their colleagues, found it impossible to continue to serve owing to pressure of other work.

TERMS OF REFERENCE

To review the practice of reinforced concrete construction of buildings, and to make recommendations which will ensure in the post-war period the greatest practicable economies of material and the most rapid methods of construction, due regard being paid to the interrelated requirements of modern building, such as lighting, ventilation, plumbing, etc.

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NO. 11

ELECTRICAL INSTALLATIONS

BY

A COMMITTEE CONVENED BY

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INSTITUTION OF ELECTRICAL ENGINEERS

THE ELECTRICAL INSTALLATIONS COMMITTEE

To the Right Honourable Lord Portal of Laverstoke, D.S.O., M.V.O., Minister of Works

MY LORD, We were convened in June 1942 by the Council of The Institution of Electrical Engineers, who were acting in response to an invitation from yourself. Our study was to be part of a scheme inaugurated by Lord Reith, when Minister of Works and Planning, with the object of securing a comprehensive and co-ordinated review of building technique for the guidance of those who would be responsible for the direction and organization of building after the war.

We were charged with that part of the general scheme which related to Electrical Installations in Buildings. Our Terms of Reference within this study of building were as follows :

1. To review existing information and practice concerning installations in buildings for :
   a. the supply of electricity for all purposes from the point of entry of the current at the property boundary to the point of its delivery to an appliance;
   b. electrical household appliances serving the single family dwelling; and
   c. all forms of electrically operated telecommunications.
2. To review proposals for improved electrical appliances for space heating, cooking, refrigeration, hot-water supply, dish washing, and clothes washing.
3. To make recommendations for practice in post-war building.

Twenty-two full meetings of the Committee were held, and to enable the extensive field of our work to be covered expeditiously we set up five Study Panels, which made preliminary investigations, on the basis of which we completed four first draft reports covering different aspects of our work. These were circulated to appropriate bodies and the comments received have been of great value to us in completing our final report. The Study Panels were constituted mainly from the Committee itself, but, in addition, several gentlemen whose specialized knowledge has been of the greatest value to us accepted membership of one or other of the Study Panels, and we wish in this connection to put on record our thanks to Mr. C. A. Cameron Brown, B.Sc., A.M.I.E.E., Mr. L. W. Hayes, O.B.E., M.I.E.E., Mr. H. S. Hine, M.B.E., Mr. E. A. Mills, M.Inst.C.E., M.I.Mech.E., M.I.E.E., Mr. F. C. Raphael, M.I.E.E., Mr. Walter Riggs, M.B.E., M.I.E.E., and Mr. H. D. Walston.

We have been fortunate in having Scottish representation on the Committee, and the proposals made in the report may be regarded as being generally applicable to Scottish conditions and requirements.

Having completed the study of the problems referred to us, we have pleasure in presenting our report.

We have the honour to be

Your Lordship's obedient servants,

JAMES R. BEARD, *Chairman.*	H. G. S. PECK.
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J. M. KENNEDY.	V. WATLINGTON.
H. MARRYAT.	E. B. WEDMORE.
S. E. MONKHOUSE.	J. FLOOD.

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GLOSSARY OF PROPOSED NEW STANDARD TERMS

With a view to reaching uniformity of terminology for all services, so that ambiguity in references between architects and others may be prevented, the following proposed new standard terms have been agreed by the interests concerned, and are used throughout this Report:

MAIN.	The undertaking's pipe or cable in the street.
CONTROL.	The stopcock, main switch, or tap controlling supply from the undertaking to the user.
SERVICE PIPE OR CABLE.	The connection between main and control.
INTERNAL INSTALLATION.	All pipes or cables on the consumer's side of the control.
CONSUMER'S SUPPLY CONTROL.	This term has been adopted by the Electrical Installations Committee to denote the electricity undertaking's service apparatus, and the consumer's main switch and fuses.

WIRING REGULATIONS

The Wiring Regulations to which reference is made throughout the Report are The Institution of Electrical Engineers' Regulations for the Electrical Equipment of Buildings (11th Edition: revised: December, 1943).

ELECTRICAL INSTALLATIONS

A REPORT BY A COMMITTEE CONVENED BY
THE INSTITUTION OF ELECTRICAL ENGINEERS

INTRODUCTION

1. The importance of engineering services in buildings of to-day may be conveniently epitomized by a brief comparison of the engineering installations of a house of the last century with those of a house of to-day.

2. A good house of those days was provided with water supply, originally to serve the kitchen, and later to provide sanitary facilities, and a cold and hot-water supply to the bathroom—itself an innovation. A bell system operated by wires and pulleys was installed. In the later years of the century gas and, subsequently, electric light installations became common.

3. A good house of to-day may contain as normal requirements a complete cold and hot-water installation, an electric bell system, and installations providing lighting and energy for cooking, main, and auxiliary water heating, refrigeration, space heating, and many other daily needs, ranging from labour-saving appliances such as the vacuum cleaner to amenities such as the radio and telephone.

4. The corresponding development in business premises and other large buildings is equally significant, since in modern buildings engineering services play a dominant part in determining the space utilization in the basement, and the space requirements of lift wells and service ducts, and in serving the well-being and convenience of all occupants by the provision of lighting, heating, ventilation, local power supplies, telecommunications, and other facilities.

5. Progress from the earliest and most elementary engineering installations to the most modern has occupied many years, in which the impact of many new developments may be clearly traced. In the field of electrical installations The Institution of Electrical Engineers' Regulations for the Electrical Equipment of Buildings, now in their eleventh edition and their sixty-second year, provide a historical commentary on the changes that have taken place in installation practice. The Regulations from their inception have been directed towards the safe and convenient use of electricity, and there is no doubt that the high standard of electrical installations in this country is largely due to their influence.

6. Inevitably, however, the application of a new science has often resulted in the superimposition of progressive developments in buildings unfitted to receive them. All too frequently, also, buildings have been designed without due regard to the engineering services which have subsequently been required in them. Or, more positively, we have in general failed to design buildings to take advantage of modern advances in applied science. To revert to the domestic example, although the nineteenth-century basement kitchen is regarded as obsolete, we have failed to design kitchen premises to take full advantage of modern labour-saving fittings and equipment.

7. The attainment of engineering installations of an inherently satisfactory standard is primarily dependent on early, full, and progressive co-operation and collaboration between the architect and the engineering and other interests concerned at all stages of planning and construction. Indeed, we are of the opinion that *only by means of effective co-operation and collaboration will it be possible to secure for the community, now and in the future, the full advantages of technical progress*. We have noted with interest and wish to support the full statement on this matter contained in the Report of the Mechanical Installations Committee (No. 9 in this series).

8. Considered from the points of view of the electrical and telecommunications installations, the following may be concerned in the planning and construction of a new building: the owner, the occupier or his representative, the architect, the consulting engineer, the builder, the electricity supply engineer, the telephone manager, the electrical contractor, and the local municipal or other civil administration authorities.

9. We regard the present halt in building as a unique opportunity to review past experience and present developments with a view to establishing sound practice in post-war building, and we consider that the series of reports, of which this is one, dealing with the technicalities of the many aspects of building, constitutes a historic step in initiating that co-operation which, in our opinion, is essential to the healthy and happy life of the nation.

PART I. ELECTRICITY IN HOUSES AND FLATS

10. In our approach to the problem of post-war housing we have endeavoured to keep foremost in our minds the dual function of housing, namely, to provide shelter, and to provide members of every family with such amenities as shall enable them to lead happy, comfortable, and useful lives. In brief, we have borne in mind that beyond their mere shelter value post-war houses and flats will be post-war homes. The first requirements for healthy and comfortable homes are sound structure, ensuring warmth and dryness, convenient internal arrangements, and adequate equipment. Although the demarcation between a reasonable amenity and an unnecessary luxury is indefinite, we have endeavoured to reach a satisfactory solution of the problem by applying to amenities the yardstick of reasonable expenditure.

11. The great majority of the dwellings erected during the twenty years 1919–39 are included in one or other of the following groups:

i. Houses of the council type.

ii. Building estate semi-detached or detached villas.

iii. Larger detached self-contained houses.

iv. Flat residences of low and high rental, according to location and accommodation.

12. It may be expected that post-war housing will fall generally within the same categories. The main post-war domestic building programme, we are instructed, will be concerned with the houses in group (i), the smaller houses in group (ii), and the lower rental flats in group (iv). The small family houses of group (i) and (ii) may be expected to have floor areas of 850 to 1000 sq. ft. The floor areas of equivalent flats will be somewhat less than this, and flats for one or two persons will be smaller still. In view of the post-war numbers and priority of small houses and flats we have dealt exclusively with them in the following section. The additional requirements of large houses and flats are discussed in a subsequent section. Specific consideration has not been given to still larger houses—for example, of the mansion type—since these are unlikely to feature to any significant extent in post-war building and would be the subject of individual attention in any case. Many of the recommendations made for smaller dwellings are applicable to all dwellings.

13. An important basic assumption made in respect of domestic premises in general is that electricity supply tariffs will be so adjusted as to require the use of one meter only for each consumer with a correspondingly simplified wiring system.

14. A further assumption is that no electricity supply other than alternating current (A.C.) will be made available for post-war dwellings.

SECTION 1. INSTALLATIONS IN SMALL HOUSES AND FLATS

A. SERVICE AND CONTROL ARRANGEMENTS

15. Present-day methods of bringing the electricity service cable into a dwelling and of providing the consumer's supply control can, in our opinion, be improved with particular advantage in the small premises now under consideration. Proposals which simplify the consumer's supply control and reduce its cost are made.

16. Service and control arrangements in post-war housing should provide for the possibility of the full use of electricity—that is to say, every consumer should have the opportunity of choosing electricity for the purposes of lighting, cooking, water heating and occasional space heating, and for all other purposes which save labour or make for cleanliness or add to the amenities of the house, including general space heating where required. The section of service cable should therefore anticipate the ultimate loading, and the consumer's supply control should be arranged to accommodate the immediate and future requirements for the consumer's circuits and metering.

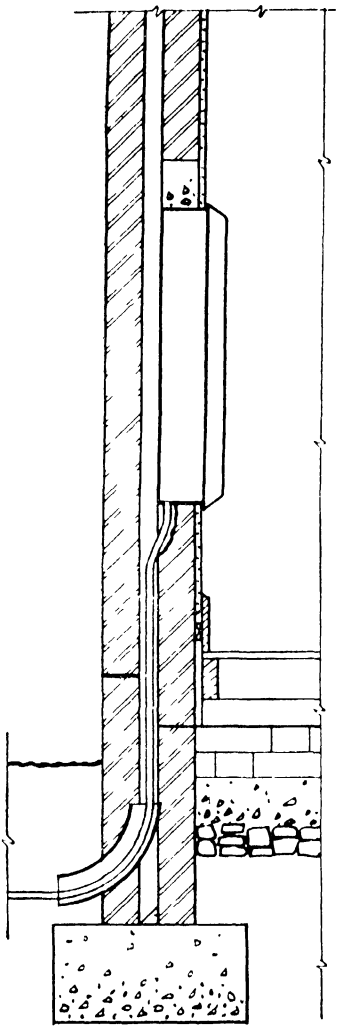
17. The early consultation emphasized in the Introduction is important in deciding the type of service to be used and its arrangement. As a general principle, for reasons of engineering and of amenity, underground service is to be preferred and should be adopted in urban districts wherever possible. From the point of view of economy and rapid application, however, overhead service may offer considerable advantages in new districts and rural areas. In this regard the method known as "under-eave construction" merits attention. (See paragraph 27.) In either case the proposed run of the undertaking's mains in relation to the proposed houses must be determined. Underground cables are usually laid in the street, and front entry of the service cable is, therefore, usually most convenient, but the nature of the undertaking's system, the housing plan, or the proposed position of the consumer's supply controls may favour entry at the backs or at the sides of houses. Where overhead services are proposed, back entry may be desirable to avoid the disadvantages of poles and overhead wires in the streets, and to secure a more desirable location of the consumers' supply controls.

SERVICE TO HOUSES FROM UNDERGROUND DISTRIBUTION SYSTEMS

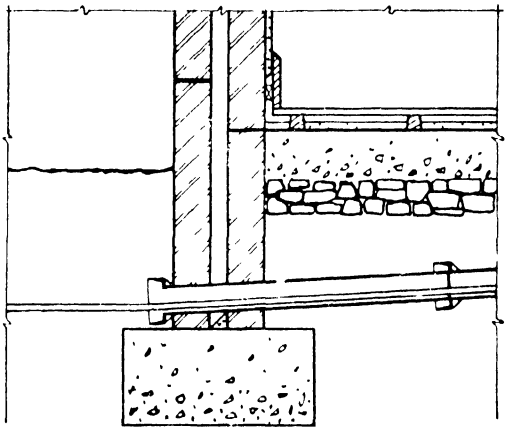
18. The minimum cross-section and type of service cable recommended as a standard is 0·0225 sq. in. twin, paper-insulated, lead-sheathed, unarmoured cable, manufactured to *B.S.* 480–1942. The continuous current rating (Wiring Regulations) of this cable is 71 amperes, providing a loading of 16 kw. at 230 volts, which should be ample for small dwellings of the types considered. The cable size may require to be increased when considerations of voltage drop arise, which may often occur when the length of the cable exceeds, say, 30 yards.

19. Service cables laid in gardens should be at a depth of not less than 18 in. to minimize the risk of damage. When laid under paths, not less than 12 in. of cover should be provided.

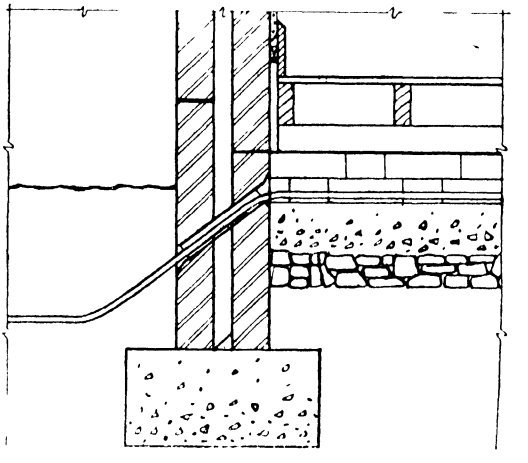
20. To avoid unnecessary cutting away and making good of walls and floors, the position of the consumer's supply control should be predetermined and proper provision made for the entry of the service into the house and its run to the chosen position. Where solid floors are proposed this is of particular importance, but, even where the joist and floor board form of construction is to be



(*a*) Cable run in cavity wall to consumer's supply control position



(*b*) Cable run in duct under concrete floor



(*c*) Cable run on oversite concrete under wood joist floor

Fig. 1. ENTRY OF SERVICE CABLE TO DOMESTIC PREMISES FROM UNDERGROUND DISTRIBUTION SYSTEM

(See paragraph 20)

used, provision for the service cable should be made to avoid disturbance of floor boards and notching of the joists. The service cable should be brought in through a duct preformed or built in for the purpose. Where the consumer's supply control is to be installed in a cavity wall immediately above the point of entry, the duct should provide for entry of the cable to the cavity as shown in Figure 1 (*a*). Where the consumer's supply control is not to be so located, a duct should be formed or embedded in the oversite concrete or run under the concrete floor to the required location as shown in Figure 1 (*b*) and (*c*). This duct may terminate in a cavity wall space as shown, or in a chase provided or cut in an internal wall, or at the spandrel understair position. Where run to a partition wall, in which recessing is not possible, consideration should be given to the provision of a half circular section housing of wood or other suitable channelling to provide mechanical protection for the cable and to minimize unsightliness. To facilitate the drawing in of the cable, the floor duct should run as directly as possible to the proposed position; bends, if these are unavoidable, should be of a gradual curvature.[1] To prevent the entry of moisture or vermin the duct should be sealed with suitable material whether or not the cable has been drawn in, and any servings on that portion of the cable beyond the exit from the duct should be removed to avoid fire risk.

SERVICES TO HOUSES FROM OVERHEAD DISTRIBUTION SYSTEMS

21. The service cable to a house from an overhead distribution system runs from the point of attachment of the undertaking's overhead supply line, through a lead-in tube to the consumer's supply control. The positions of the point of attachment, of the lead-in, and of the consumer's supply control are clearly related, and none should be fixed without reference to the positions of the others.

Point of Attachment. The point of attachment will usually be determined by the run of the overhead supply line. This, as suggested in paragraph 17, may preferably be at the backs of houses.

Consumer's Supply Control. The convenience of the consumer and the efficient layout of the consumer's installation should be given full consideration. The choice of a position at the back of a house may often be indicated on these grounds.

Lead-in Tube. The position of this will be determined by the positions of the point of attachment and of the consumer's supply control, and by the convenient run of the service cable which may be partly inside and partly outside the house.

22. The service cable should be single or twin rubber-insulated, taped, braided, weather-resisting cable not less than 0·0225 sq. in. in cross section.

23. Similar cable insulated with polyvinyl chloride (P.V.C.) would form a satisfactory alternative to which the possibility of post-war rubber shortage gives added importance.

24. The position and type of external attachments or fixtures should be discussed with the supply undertaking so that these may be supplied and fixed during building with a view to avoiding later disturbance and damage to the

[1] The minimum radius of curvature of standard 3-in. duct "bends" generally used in laying 0·0225 sq. in. cable is 10 in. This radius is, of course, only permissible when the total run is short and direct access to the bend is possible. If a long run is necessary the duct sections must be so chosen and laid as to ensure that the desired gradual curvature is obtained.

fabric. For safety reasons fixtures should be securely made to those parts of the structure capable of withstanding the stress.

25. Insulators should be of a colour inconspicuous in relation to the building.

26. The lead-in should be effected by means of a porcelain tube cemented into the wall. It should be glazed inside but unglazed outside for cementing. It should slope downwards towards the outside, and should be plugged with waterproof plastic compound or other suitable material to prevent the entry of rain.

27. Where houses are semi-detached or built in terraces, the supply undertaking should consider the use of weather-resisting cable attached to buildings by the method known as "under-eave construction." The cost of distribution, particularly on housing estates, can be reduced materially by this method. Way-leave procedure should be amended to enable undertakings to adopt this construction as a standard practice in appropriate cases. It is assumed that where the owner is a local authority the way-leave will invariably be given.

SERVICE CABLES TO FLATS

28. This matter is dealt with in Part II and Part III, Sections 1 and 2.

EARTHING

29. One or other of the following earthing arrangements for the internal installations should be made in consultation with the supply undertaking:

i. To the water-supply main where this is available.

ii. To the lead sheath, if any, of the undertaking's service cable where this is regarded as satisfactory and acceptable by the undertaking.

iii. To an effective earth electrode or electrodes, which should be subject to inspection by the supply undertaking at the time of installation, and to subsequent periodic inspections by a competent person.

iv. If the earth resistance in a locality is too high for safety to be obtained by means of direct connection to an earth electrode system, and if methods (i) and (ii) are impracticable, provision for protection may be made either by the use of an earth leakage circuit breaker of appropriate rating or by protective multiple earthing, if this method is adopted by the supply undertaking.

CONSUMER'S SUPPLY CONTROLS

30. Existing methods of installing the supply control equipment on consumers' premises have been considered, and it is recommended that a standard form of apparatus and mode of installation be adopted according to the type and size of residence to be supplied. The haphazard arrangement, often seen on consumers' premises, of different pieces of equipment of odd types and sizes attached to walls in positions regardless of convenience or appearance should no longer be tolerated.

31. If electricity meters of the same function and capacity could be standardized as regards terminal arrangements, external shape, dimensions and fixing bolt centres, the standardization of consumer's supply controls according to size of installation would be substantially facilitated.

32. Pending the development of the combined service unit or "consumer's supply control" suggested in the succeeding paragraphs, it is recommended that the type of fitting, which serves as a cable sealing box and main supply fuse box, be adopted as standard for installation in premises of ordinary consumers. This fitting can be installed in a neat and satisfactory manner, and it is produced by several makers, without large variations in dimensions. The present standard 60 ampere (nominal) unit is satisfactory for the 0·0225 sq. in. service cable recommended.

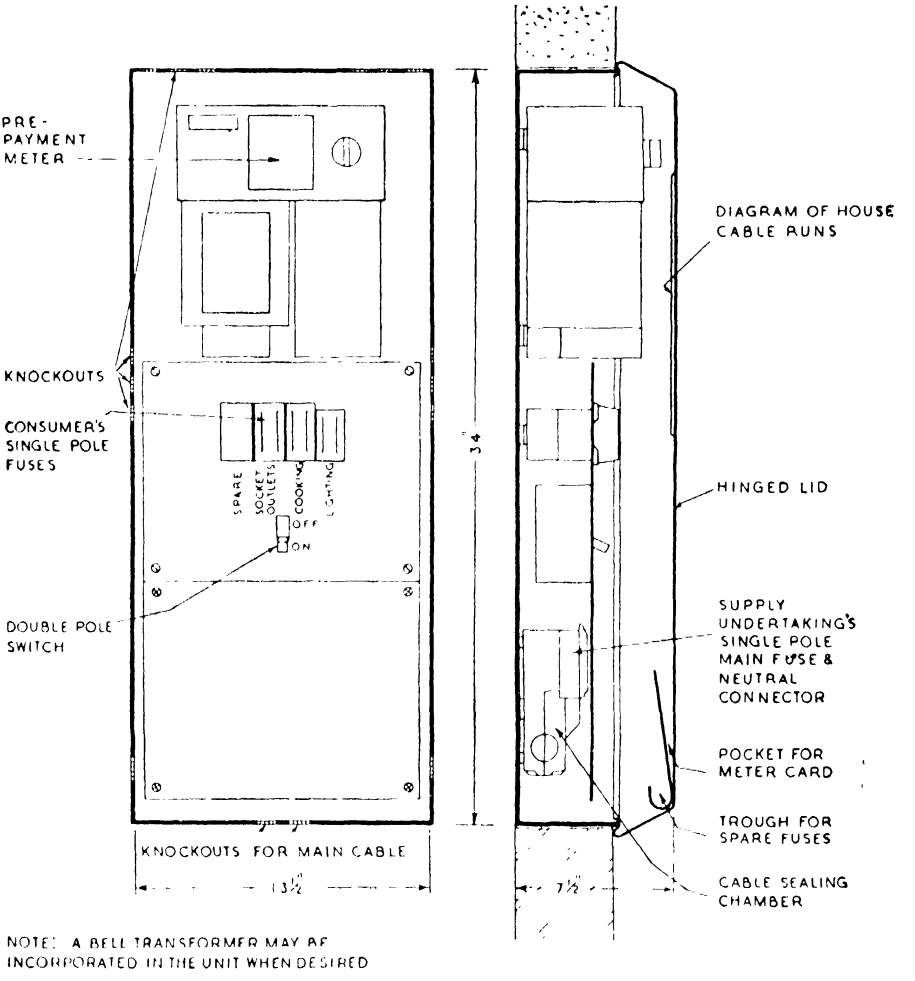


Fig. 2. CONSUMER'S SUPPLY CONTROL

(See paragraphs 34, 35)

33. On general grounds, and in small premises particularly, it is important that the consumer's supply control should be compactly arranged and housed so that it may be built into any suitable wall or panel location. For this purpose a substantial advance on existing practice can be made by compactly assembling existing equipment into a box containing the combined cable sealing box and main supply fuse, the consumer's main switch and fuses, and the meter. Such a box, fitted with a door, can be conveniently built in as required.

34. However, post-war advance should not be restricted to a mere assembly or rearrangement of existing individual items of equipment. Having regard to our recommendations for a "ring circuit" for consumer's socket-outlets (see paragraphs 76 and 77) and for fuses (see paragraph 80) and to the fact that the Wiring Regulations permit in specified conditions the omission of the consumer's main

fuse,[1] and to a recent revision of the Regulations which requires single pole fusing for installations connected to systems on which the neutral point is permanently earthed,[2] the components of the post-war consumer's supply control will be:

Cable sealing box.
Main supply single pole cartridge fuse (sealed).
One 5-amp. single pole cartridge fuse for lighting circuit.
One 30-amp. ,, ,, ,, ,, ,, cooker circuit.
One 30-amp. ,, ,, ,, ,, ,, socket-outlet ring circuit.
Space for one further (spare) 30-amp. single pole cartridge fuse.
Disconnecting link to neutral.
Double pole main switch or quick-acting circuit breaker.
Prepayment or quarterly meter with provision for the connection of a check meter.
A bell transformer, when desired.

35. A housing in which this equipment may be assembled with any existing type of prepayment meter and any existing type of the other apparatus is shown in Figure 2. The housing, which may be of pressed metal or other light metal

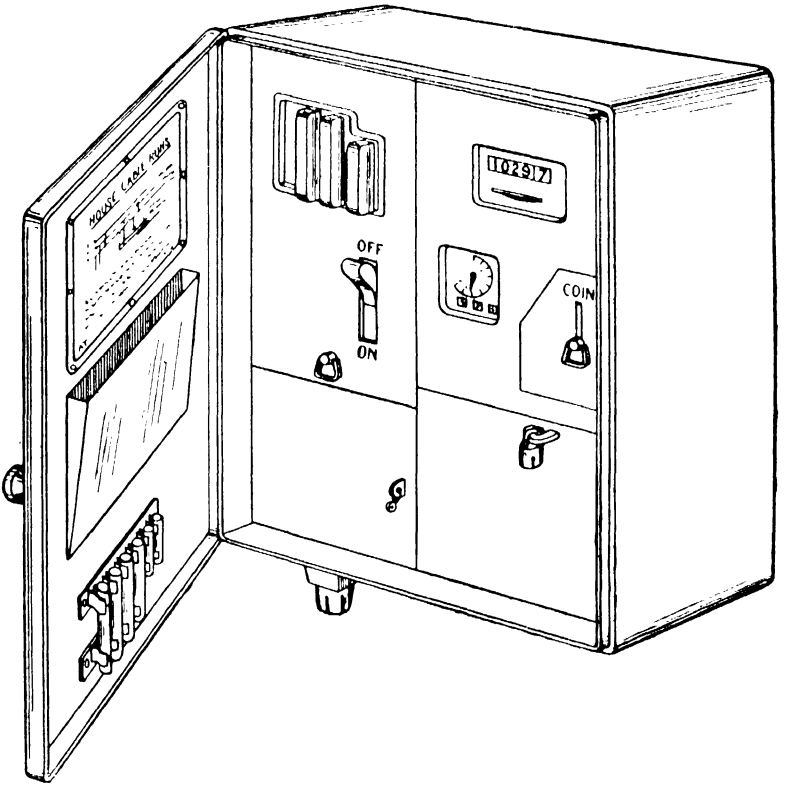


Fig. 3. SUGGESTED COMPACT DESIGN OF CONSUMER'S SUPPLY CONTROL

Overall dimensions: 14″ high, 12″ wide, 5″ deep (See paragraph 36)

[1] Wiring Regulations 105 and 106 (c).
[2] Wiring Regulation 112.

construction or of plastic material, is 34 in. high by 13½ in. wide by 7½ in. deep, and may be conveniently recessed in a wall to a depth of 4½ in., *i.e.* a brick-depth. The door of the unit is hinged. It is recommended that a diagram showing the positions of the cable runs of the internal installation should be mounted on the inner side of the door, which should also accommodate spare 5- and 30-ampere fuses, and a pocket for meter register cards. The outer side of the door should be finished to have an appearance in keeping with its location in the house. We recommend that the possibility of standardizing a unit generally in accordance with this proposal should be considered. The dimensions of the housing should be related to standard brick dimensions, so that the unit may be conveniently built into a wall.

36. We consider that the ultimate objective is a more compact unit to be obtained by using specially designed and standardized components assembled within a metal or plastic case. Such units would require considerably less space and would have a greatly improved appearance. A sketch of a unit such as might be developed is shown in Figure 3. We wish to emphasize our conclusion that such units should be made available as soon as possible and that in the design stage the opportunity should be taken to standardize their external shape, fixing and terminal positions, and fusing arrangements.

37. Units of this description should preferably be built in, but in view of their good design and appearance they might be directly wall mounted in circumstances in which recessing presents difficulties.

38. Having in mind the need for rapid post-war construction, supply controls as recommended would offer the advantages of mass production, and would be a factor in reducing installation work in the consumer's premises.

LOCATION OF CONSUMER'S SUPPLY CONTROL

39. In the small residence the supply control is often placed over or behind the front door. Neither position is suitable. The first is inaccessible, and the second incurs the risk of damage. Another favourite place is in the space under the staircase, generally used as a lumber hole; miscellaneous material then becomes piled against the equipment, making access difficult.

40. By incorporating one of the suggested standardized supply units in a convenient position during the building operation this state of affairs can be remedied. An internal wall or the understair space can provide accommodation, the latter by mounting the supply control unit flush with the spandrel understair face with the door opening into the passage. The fire-resisting case of the control unit will isolate it from the remainder of the understair space.

41. The position chosen for the control unit should be well lit, and should allow the insertion of coins and the reading of the meter without climbing or unreasonable stooping.

RELATION TO OTHER SERVICES

42. A common approach trench and entry for services from the street mains into a house is unnecessary and should not be sought as an end in itself. Where, however, the layout of street mains makes a common approach trench or duct and point of entry convenient and economically desirable, these may be arranged, provided service pipes and cables are properly insulated from one another. They should be carried through the structure wall in suitable sleeves, located together and preformed or built in for the purpose, or, alternatively, in a preformed or built-in multiple duct designed for the purpose. The approach and entry of water, gas, electricity, and telecommunications services may be treated in this way, though the water service may generally and preferably be brought in quite separately.

43. Beyond the common point of entry, when this is adopted, the different services may continue to run in a suitable common duct if the chosen locations of the supply controls make this convenient. Provided the services are properly insulated from one another, there is no objection to this practice.

44. The desirability and practicability of housing the consumer's electricity supply control with the controls of other services has received our close attention. Common housing is not an objective in itself. We consider that in small dwellings the electricity consumer's supply control should be located approximately at the centre of load of the installation to facilitate the convenient and economical layout of the wiring runs. The entering service cable may be brought to any convenient point for this purpose. Furthermore, the provision in a small dwelling of two small cupboard recesses or positions, rather than one larger one, may frequently be more convenient architecturally. However, where the layout of the internal installations justifies a common location for the gas and electricity supply controls, we consider these may be satisfactorily housed in adjoining enclosures, provided both are separately ventilated to avoid moisture condensation and to ensure against the possibility of an inflammable atmosphere being ignited by an electric spark. The adjoining enclosures may be arranged as cupboards with separate doors, designed to present a uniform and pleasing external appearance. Suitable ventilation may be provided in the doors by louvres or other means. One door giving access to both supply controls might possibly be used if an effective gas-tight partition between the controls were provided within the enclosure.

B. INTERNAL INSTALLATIONS IN SMALL HOUSES AND FLATS

EXTENT OF ELECTRIFICATION

45. In planning the nature and extent of the internal installation, it is necessary to make provision for the consumer to derive full benefit from the many facilities that may be provided electrically, by arranging for a reasonable choice of positions in which appliances may be connected. The main applications are considered below, and for convenience may be listed as follows:

a. Lighting.
b. General domestic applications.
c. Occasional fires.
d. Cooking.
e. Water heating.
f. Refrigeration.
g. General space heating.
h. Laundering.

a. LIGHTING

46. This matter is dealt with in the Report of the Lighting Committee,[1] with whom full co-operation has been maintained. For convenience, however, the fixed lighting requirements of small dwellings may be summarized as follows:

> Two lighting points in the kitchen (one controlled by two-way switching where there is more than one entrance), and at least one lighting point in each of the other rooms, including the bathroom and lavatory, and in the hall and landing, provision in this case being made for two-way switching. The understair cupboard, loft and cellar, back and front doors, should all have light points. Provision should also be made for the separate illumination of the larder and large cupboards. The need for lights in shallow cupboards may not generally arise in small houses and flats, provided care is taken to hinge the doors of such cupboards so that on opening they shall not screen the natural and artificial illumination.

[1] Post-war Building Studies No. 12: *The Lighting of Buildings.*

47. We concur in the view of the Lighting Committee that dwellings such as those now under consideration should have lighting fittings, which will give reasonable performance, installed complete with lamps of the correct wattage, as part of each consumer's installation.

48. Where low ceilings are adopted, ceiling-mounted fittings may generally be desirable, and should, in any case, be used in kitchens, bathrooms, wash-houses, stores, lavatories, and porches. Pendant fittings may be used in living rooms and parlours. For wall mounting—for example, over bathroom mirrors or kitchen sinks—all-insulated or earth-connected bracket fittings may be used provided they are satisfactorily fixed with screws to their wall-connector boxes. Fittings for outside lamps should be of robust weather-proof design and arranged for conduit entry, or, alternatively, for fixing directly on to a connector box.

b. GENERAL DOMESTIC APPLICATIONS

49. Socket-outlets will be required for standard lamps, radio, clocks, toaster, vacuum cleaner, iron, and other small appliances. Pre-war installations were generally already inadequate for the rapidly increasing number of these small consumption appliances, and a marked development in the use of new devices of this nature may be expected after the war. Greater progress in this direction has been made in the United States where there are numbers of small power devices in any ordinary home, *e.g.* mixers, polishers, razors. Mass-production methods may make such equipment generally available in this country. These are developments which may reasonably be expected, and which the provision of general utility socket-outlets should anticipate.

c. OCCASIONAL FIRES

50. Provision for the occasional use of small radiant electric fires, and, possibly, a kettle, would not usually require any additional wiring over and above that required for (b) above. In fact (c) might be considered by some as included in (b), and it is only mentioned separately to emphasize the fact that the installation should allow the occupier to use electricity, if he so desires, for providing "topping up" heat.

d. COOKING

51. Prior to the outbreak of war there was a rapid increase in the number of electric cookers installed, and as a result of war-time experience we consider that the potential demand has been increased.

52. Large numbers of small houses have in the past been fitted with solid fuel fires on which cooking can be done, but despite this provision it is found that an independent cooking appliance is almost invariably considered desirable. For those engaged in occupations for which an early start is necessary a rapid cooking appliance is of particular convenience.

53. The choice of medium must be the concern of the consumer, and having regard to this consideration it is recommended that full provision for electric cooking in post-war dwellings should be made by wiring to a suitable cooker position in each kitchen. Alternatively, conduit should be run to the cooker position so that the wires may be drawn in when required.

54. The features and dimensions of proposed cookers are given in Part I, Section 3, on electrical domestic appliances (paragraphs 174–177 and Figure 6).

55. We recommend that the cooker control unit should be separate from the cooker, and that it should be mounted on the wall near the cooker. With regard to the provision of a socket-outlet in the control unit, the danger arising from the risk of burning the flexible cord on the cooker hot-plates has been considered, and it is thought that this should be avoided by so placing the cooker control unit that the electric kettle or other appliance can be stood on a dresser or other suitable shelf. With this arrangement in view we consider that a socket-outlet should be provided in the cooker control unit. This socket-outlet would be supplied from the cooker circuit and would be independent of the other kitchen socket-outlets recommended in paragraph 72.

e. WATER HEATING

56. The use of electricity for water heating is of more recent growth than electric cooking, but large numbers of installations are in use. Their cleanliness, compactness, labour-saving qualities, and low maintenance cost (even in hard water districts) are factors which are likely to result in their increasing use in the future.

The three principal types are:

i. The open outlet non-pressure heater for local use above a sink or in a bathroom.

ii. The electric pressure or cistern heater supplying hot water to more than one point in a dwelling.

iii. The immersion heater in the hot-water storage tank, used for "topping up" and for summer use, in a system designed for heating by a solid fuel fire.

57. The capacities, dimensions, and ratings of the various types are given in Figures 9 and 10.

58. A number of designs of heaters of type (i) are available in various sizes from 1½ to 20-gallons capacity. These heaters have the advantage of requiring little adaptation of an existing plumbing system and would be connected to the ring circuit (proposed in paragraph 76), usually through a switched socket-outlet. Care should be taken to ensure satisfactory earthing.

59. In the small premises under consideration the small amount of pipe-work and the small number of draw-off points make water-heaters of type (ii) particularly suitable. Such heaters are available in sizes up to 30-gallons capacity, but for small dwellings we advocate the design of a multiple unit heater of 20-gallons capacity, which could be installed in a convenient position, such as below the sink draining board or in an adjacent kitchen cupboard, so that the pipe-runs to kitchen and bathroom would be as short as possible. Such a water-heater would be fed directly from the main cold tank in the roof and should be so designed that small quantities of hot water at the top of the tank might be made available without heating the entire contents; for this purpose one heater unit of ½ kw., controlled by a thermostat, could be permanently in circuit to provide sufficient water for ordinary domestic use. The main unit, of higher rating, and heating the whole tank, would be switched in when baths were required. By concentrating on efficient lagging of the tank and piping and relinquishing any attempt to use waste heat for clothes airing (which should be carried out in the drying cupboard referred to in paragraph 71) a water-heating efficiency of the order of over 95 per cent is attainable. Combined with a tank temperature of about 160° F. the capacity should be ample for small houses and flats.

60. In dwellings where either an open or closed solid fuel fire is desired, there should be provision for a thermostatically controlled immersion heater (iii above) in the hot-water storage tank for "topping up" and for summer use. We therefore recommend that tanks and cylinders for such systems should be provided with bosses for the insertion of the immersion heater-thermostat units at the most effective positions and that consideration should be given to the standardiza-

tion of the fixing arrangements of such units. Tanks and cylinders should have height in preference to width, *i.e.* rectangular tanks should be placed "on end," and at least 3 in. space on all sides and on the top and bottom should be allowed for the application of an effective thermal insulating covering. Adequate clearance must also be provided between the tank and the cupboard door or walls for the head of the heater-thermostat unit and for its convenient insertion and adjustment. As an alternative arrangement, a 20-gallon electric water-heater fitted with two heater-thermostat units as described in the preceding paragraph may be coupled to the solid fuel boiler for complementary use therewith, and in place of the usual hot-water storage tank.

61. In domestic hot-water systems, whether all-electric or with auxiliary electric heating, the following points, which will no doubt have been considered by the Plumbing Committee, should be borne in mind:

i. Hot-water pipe-runs should be as short as possible so as to minimize heat losses.

ii. Stop valves, if inserted between the cold and hot storage tanks, should be of the gate or full-way type, and not of the bib-cock or screw down type (fitted with the loose jumper) as this latter type functions as a non-return valve and also introduces a very substantial degree of resistance, which retards the flow of water.

iii. The installation should be so designed that reversed or other undesired circulation through the pipe-work cannot occur when the heater is in use.

iv. Each installation should be restricted to one type of metal, *i.e.* all-galvanized or all-copper. In no circumstances should ungalvanized mild steel pipe be used.

f. REFRIGERATION

62. On grounds of health, to eliminate wastage of foods, and as an aid to good catering, the refrigerator is coming to be regarded as a valuable domestic asset. It is recommended that refrigeration facilities be provided; for these the energy consumption involved will be small. A storage capacity of 4 cu. ft. is recommended. An appliance of the built-in type is envisaged which could be conveniently contained in a recess provided for the purpose in the kitchen wall cupboards. The dimensions and arrangement of the refrigerator are given in paragraphs 178 and 179 and Figure 7 respectively. With a refrigerator of this capacity, consideration may be given, particularly in flats and urban houses, to the reduction of larder space. The "north wall" restriction in larder siting may also be avoided where provision is made for refrigeration.

63. Refrigerators of the recommended capacity could be provided more cheaply for post-war use in this country if standardized and mass produced.

g. SPACE HEATING

64. With a view to effecting economy in heating dwellings early consideration should be given to their thermal insulation characteristics. This matter and the entire problem of space heating is dealt with in the Report of the Heating and Ventilation Committee (No. 19 in this series).

65. Bearing in mind the limited cubic capacity and the load diversity of the small dwellings under review, we consider that they could be adequately heated electrically, using portable or inset radiant electric fires or convectors up to 2 kw. rating supplied from the ring circuit. (See paragraphs 76 and 77.) In small rooms the use of inset fires should be avoided in view of the limitations they impose on the location of furniture and the danger of scorching adjacent woodwork or bedding. Where socket-outlets are to be provided, consideration should be given

to the omission of chimney fire-places and flues, which it is thought may partially offset the cost of the internal installation.

66. Various types of radiant electric fires and electric convectors generally in accordance with pre-war practice will be available. It is recommended that the dimensions of these appliances should be correlated to the proposed standard openings of solid fuel fire-places so that, when desired, they may be placed in solid fuel fire-places to form a unified and pleasing arrangement.

h. LAUNDERING

67. In small houses, particularly in the north of England and in Scotland, home laundering is customary. Large numbers of electric wash-boilers are in use throughout the country, and electric washing machines and wringers were also becoming widely used in the immediate pre-war years. On grounds of labour saving we consider that home laundering equipment will be increasingly required in the post-war period, and we therefore recommend that in all new houses, and particularly in rural houses, the space and layout of the kitchen premises should provide adequately for a wash-boiler and washing machine. The washing machine described in paragraph 181 and illustrated in Figure 8 is mounted on castors, and with the wringer unmounted, may be conveniently kept under the sink draining board. The overall dimensions of wash-boilers and of this washing machine are given in paragraphs 180 and 181. These appliances may be connected permanently to wall connector boxes by means of flexible cable enclosed in flexible steel tubing, designed to ensure satisfactory permanent earthing of the appliances. For convenient use a tap, possibly a swivel tap from the sink, should be arranged for filling the machine or boiler with hot water. In addition some convenient provision should be made for piping the used water to, say, the kitchen sink outside gully.

68. In flats individual laundering equipment may not always be regarded as desirable. The effects of steam substantially increase the cost of redecoration, and the drying of washing in flats always presents difficulties. For such premises the space and layout of each kitchen may be designed to accommodate a wash-boiler and washing machine, or alternatively, communal laundries may be provided. Experience has shown that where these are adequately equipped the great majority of families make use of the facilities.

69. The trend towards the use of lighter clothing made of rayon or similar new fabrics is an important factor in lessening the labour formerly associated with household laundering. An adequate supply of hot water is the principal requirement for laundering "smalls" of this nature.

70. Ironing will generally be done in the kitchen. This is usually a right-handed operation, and the position of the ironing board in relation to the kitchen socket-outlets should be considered from this point of view.

71. Provision for home laundering should include a built-in drying cupboard. This is particularly necessary where there are young children, and in rural areas where the drying of workers' and school children's wet outdoor clothing may otherwise present difficulty. A socket-outlet and plug would be required for the connection of a suitable heater or fan heater. Ventilation of the cupboard should of course be provided.

PROVISION OF SOCKET-OUTLETS

72. In post-war homes in which accent will be laid on labour saving and cleanliness, full advantage should be taken of the convenience and flexibility of electricity. It is therefore strongly recommended that an adequate number of socket-outlets of one national standard (see paragraphs 91 to 93) be provided for the connection

of portable domestic appliances. As a general guide the following is recommended as a minimum:

Living rooms:	Three standard socket-outlets.
Double bedrooms:	Three ,, ,, ,,
Single bedrooms:	Two ,, ,, ,,
Kitchen:	Three ,, ,, ,, on the ring circuit. (One of these may be omitted in kitchens not intended for use as living rooms.) And, in addition, one connection for cooker and one connection for refrigerator.
Water heater:	One connection to be provided in desired location.
Laundering:	Socket-outlets to be provided according to the laundering facilities required.

POSITIONS OF SOCKET-OUTLETS AND LIGHT SWITCHES

73. We recommend that all switches controlling lighting points should be fixed 4 ft. 6 in. above floor level, and that those in rooms be placed at a distance not exceeding 9 in. from the architrave of the door opposite to the hinged side. Switches should be of the flush-mounting or semi-recessed types. All switches should be reasonably silent in operation. Hall and landing switches should be placed in convenient relation to the staircase. The bathroom light switch may be wall mounted, provided it is out of reach of a person standing in the bath. Should this not be so, a cord-operated ceiling switch, or alternatively, a wall switch placed outside the bathroom door should be used. To prevent switch cover-plates working loose they should be positively located and fixed. In kitchens, bathrooms, wash-houses, and outbuildings, gaskets should be fitted between switch plates and boxes to prevent entry of moisture. Socket-outlets should be located not less than 5 in. and preferably as high as 9 in. above floor level, except in kitchens, sculleries, wash-houses, or other outbuildings, where the height above floor level should be 4 ft. 6 in. In these locations gaskets should be used as recommended for switches.

SWITCHES

74. *Wall Switches.* We recommend that a British Standard should be prepared covering the fixing holes and terminal centres of wall switches, the overall dimensions of the box including the cover-plate, the method of attachment of the cover-plate, and also the height of the switch in relation to the depth of the box. Consideration should also be given to the need for gaskets between switch-plates and boxes to prevent entry of moisture in locations such as those mentioned in the preceding paragraph.

75. *Cord or Chain-operated Switches.* We recommend that a British Standard covering this type of switch should be prepared.

INTERNAL INSTALLATION

76. We recommend that small dwellings of the types considered should be wired with three separate circuits for lighting, cooking, and socket-outlets respectively, each controlled by a separate single-pole fuse. It is proposed that all socket-outlets should be supplied from a "ring circuit" which, starting and ending at the fuse terminal at the consumer's supply control will pass through each room in turn. In the small dwellings under consideration it is considered permissible to connect up to twenty of the proposed standard socket-outlets on the ring circuit. At the consumer's supply control the ring circuit will be fused for 30 amperes, a current which is unlikely to be exceeded in the conditions of load diversity met with in small dwellings. At each outlet position on the ring circuit it will be necessary to provide a cartridge type fuse for local protection. (See paragraphs 85–87, and 94.) These proposals involve no departure from

established practice in the lighting and cooker circuits. With regard to the socket-outlet circuit, the recommendation to connect a number of standard socket-outlets on a ring circuit represents a departure from existing practice as laid down in the Wiring Regulations.

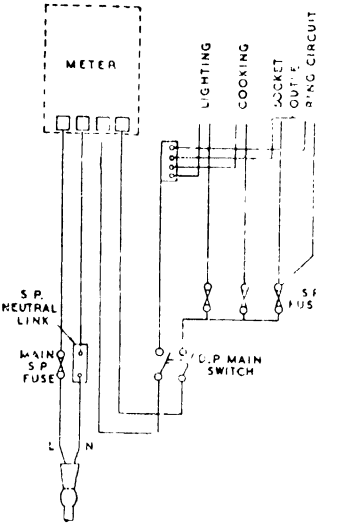


Fig. 4. CONSUMER'S SUPPLY CONTROL CIRCUIT

(See paragraph 76)

77. The provision ot circuits may be summarized as follows:

	Number and diameter (in.) of wires	Current rating amperes (Wiring Regulations)
Lighting circuits	1/·044	5
Socket-outlet ring circuit	7/·029	15 (*ring* circuit)
Cooker circuit	7/·036	29

It is intended that the ring circuit may be used not only for heating and other appliances, but also for standard lamps. A water heater of rating up to 3·5 kw. may be connected on the ring circuit. Where provision is to be made for a wash-boiler of similar rating, in addition to a water heater, this may also be supplied from the ring circuit which should be increased in rating appropriately.

78. As an alternative to the ring circuit it has been suggested that a separate circuit, fused for, say, 15 amperes, should be run from the consumer's supply control to each principal room and should feed all the socket-outlets in the room. This scheme is attractive as compared with pre-war practice but is less flexible in installation than the ring circuit, provides less flexibility in loading and, except possibly in the smaller type of house, is not so economical.

SAVING EFFECTED BY RECOMMENDED CHANGE IN PRACTICE

79. A comparison of the cost of providing the internal installation described above for a typical small house, (*a*) in accordance with pre-war regulations and (*b*) by the proposed ring circuit and single-pole fusing, shows a saving of approximately 25 per cent in favour of the latter (both estimates being referred to pre-war price levels).

MAIN FUSES

80. It is noted with satisfaction that single-pole fusing has already been approved as standard practice in areas where the neutral is solidly earthed. The recom-

mendation is now made that in the future re-wirable porcelain fuses should be discouraged and that their place should be taken by standard enclosed cartridge-type fuses. The universal use of fuses of this type would ensure adequate replacement stocks at a very small cost per fuse. Provision should be made in the consumer's supply control for storing spare 5- and 30-ampere fuses. Accommodation for these and for the spare local fuses (see paragraph 85) should be provided on the inner side of the door of the unit.

SOCKET-OUTLETS AND PLUGS

81. We have reviewed the evolution of these accessories and the reasons for the adoption, by some supply undertakings, of socket-outlets and plugs which are not in accordance with a British Standard. Experience has shown that the present three standard sizes (*B.S.* 546) of three-pin socket-outlets and plugs suitable for domestic use, rated respectively at 2, 5, and 15 amperes, have not been wholly satisfactory from the standpoint of the convenience of the consumer. The absence of an intermediate size between 5 and 15 amperes, and the cost and dimensions of the 15-ampere standard, have contributed to the use of non-standard socket-outlets and plugs to fill a gap in which there is a substantial demand. This particularly applies to the smaller classes of dwellings in which 2-kw. radiant electric fires are commonly used, and in which fires or other appliances exceeding this rating are seldom required due to the limitations imposed by the size of the rooms.

82. The present interruption in building and the predominance of the small house in immediate post-war plans provide good reasons for reviewing the matter now. In order to give the maximum convenience to the consumer, and to make the best use of the recommended ring circuit, an "all-purpose" socket-outlet and plug is an essential requirement.

83. We, therefore, recommend that, particularly having regard to the needs of the smaller type of house, a standard three-pin domestic socket-outlet and plug, intermediate in capacity between the existing 5-ampere and 15-ampere standards, should be made available.

84. The following points should be considered in deciding the design of the proposed standard:

i. To ensure the safety of young children it is of considerable importance that the contacts of the socket-outlet should be protected by shutters or other like means, or by the inherent design of the socket-outlet.

ii. To reduce the liability to damage socket-outlets should be of the flush-mounted or semi-recessed types.

iii. On A.C. circuits, which we have assumed will be universal in new buildings, disconnection can be safely made by withdrawing the plug; the expense and complication of a separate switch is therefore unnecessary in the standard design. It may, however, be desirable to have an alternative standard design incorporating a switch for use where this additional convenience is required.

iv. The socket-outlet connection terminals should accommodate a 7/·029 in. cable looped in and out and also a "spur" connection if required. Particular attention should be given to the size of the terminals and cable anchorages in both the plug and the socket-outlet.

v. In view of our recommendations that socket-outlets should be placed well above floor level, the plug should be standardized with the flexible connection entry at the bottom.

vi. The resilient members of the combination should be located in the socket-outlet as specified in *B.S.* 546, but the floating tube may not be the best method of obtaining a positive contact under all conditions, and

has been to some extent responsible for the preference for flat pins which has been shown in some quarters.

vii. Round pins should not be slotted, as the original need for providing for the use of the plug with early types of socket-outlet with non-resilient contacts is no longer important.

viii. It is desirable, if possible, that the new standard socket-outlet should not necessitate a new standard type of connecting box.

LOCAL FUSES

85. Our recommendation for a ring circuit connected to a single 30-ampere fuse necessitates arrangements for fusing at each point of outlet. This is also desirable for the alternative of room circuits. We recommend the use of cartridge-type fuses for this purpose.

86. The decision whether this fuse should be located in the socket-outlet or in the plug necessarily influences the proposed design. There are advantages peculiar to each method. From the point of view of convenience of the consumer, the incorporation of the fuse in the plug has advantages if it can be done with safety and without making the plug unduly bulky. It also has the advantage of directly associating the fuse with the attached connecting cable and appliance which constitute the potential risk, and of permitting the use of a fuse with a rating related to that of the appliance and its cable. The arrangement would, however, make it necessary to avoid the use of any existing standard pin spacing, as otherwise consumers would be able to use unfused plugs in unfused socket-outlets; moreover, even if a new pin spacing were adopted there would always be the possibility of non-fused plugs being sold. The alternative of incorporating the fuse in the socket-outlet has the advantage that in this position the protection becomes a permanent part of the installation and provides protection in all circumstances, particularly against an overload on the socket.

87. It should be impossible to remove the fuse without withdrawing the plug, whether the fuse is incorporated in the socket-outlet or in the plug. The removal and renewal of the fuse must be possible without risk of shock, and in this regard it should be noted that if the fuse is incorporated in the socket-outlet a fuse carrier may be required involving two extra contacts.

ALTERNATIVE DESIGNS CONSIDERED

88. The proposed standard domestic three-pin socket-outlet and plug may be obtained in many ways, and detailed consideration has been given to the following alternative arrangements:

i. With round pins and the fuse provided in the socket-outlet.
ii. With round pins and the fuse provided in the plug.
iii. With flat pins and the fuse provided in the socket-outlet.
iv. With flat pins and the fuse provided in the plug.
v. As (i) but with the spacings and dimensions of the pins conforming to *B.S.* 546.

89. The last alternative was included because we have satisfied ourselves that many existing designs of 5-ampere socket-outlets and plugs to *B.S.* 546 can be safely uprated to 10 amperes, and the adoption of this existing standard in respect of its pin dimensions and spacing would avoid the introduction of an entirely new standard. An incidental advantage is that consumers coming to new houses with appliances already fitted with 5-ampere plugs of this type would not be put to the inconvenience of changing their plugs. But since plugs of this type only came into general use in the last decade, undue importance has not been attached to this point.

90. All existing designs of 5-ampere socket-outlets and plugs are not necessarily suitable for uprating to 10 amperes, and most switches associated with them are not. If this alternative were adopted, it might therefore be desirable that the new standard 10-ampere plug should not be suitable for use in the old standard 5-ampere socket-outlet.

91. Having in mind that the extent of the use of the new standard will probably amount to many millions, we recognize that the correct decision between these alternatives is a matter of far-reaching importance. Such a decision is exceptionally difficult owing to the fact that each has its definite advantages and disadvantages; but it is necessary to guard against over-emphasizing these. The general benefit to be obtained from the widest use of a single standard is so great as to call for the subordination of individual preference, or even of comparatively minor technical considerations, to the choice of the alternative most likely to meet with general acceptance.

RECOMMENDED STANDARD SOCKET-OUTLET AND PLUG

92. A majority of the Committee have reached the conclusion that this result is most likely to be achieved by the adoption of alternative (v) and that a satisfactory technical design can be developed. This majority recommend that the British Standards Institution should be requested to undertake the preparation of a new standard specification for a 10-ampere, fused, shuttered socket-outlet and plug with round pins of spacing and dimensions conforming to *B.S.* 546 and incorporating the other design requirements to which reference has been made.

93. A minority, however, wish to postpone a decision until alternative designs and models of the proposed uprated 5-ampere socket-outlet and of new socket-outlets and plugs can be made available. This minority attach less importance to the principle of the adaptation of an existing standard, and feel that a better design both technically and economically might be produced if present standards were ignored. This might enable a 3 kw. (13 ampere) rating to be adopted.

(Note: A unanimous conclusion has since been reached and is given in the Appendix on p. 87.)

FUSE SPECIFICATION

94. The 5- and 30-ampere fuses, and the local fuses, referred to in the preceding paragraphs, should be of the same standard of performance as those of category 3 (*B.S.* 88). Fuses of different ratings should not be interchangeable.* The ratings should be clearly and indelibly marked on each fuse, and it should be readily possible to distinguish between a new and a "blown" fuse by the appearance.

* (But see Appendix for the special case of fused plugs.)

SYSTEMS OF WIRING

95. Having reviewed past experience and present trends, we have reached the conclusion that the wiring should be carried out in vulcanized rubber-insulated cable[1] run in screwed or lug-grip-jointed light gauge welded or brazed steel conduit. This, if properly installed, gives ample and permanent electrical conductance and screening together with mechanical rigidity, and provides a system which is preferable to any of the alternative methods or systems. It is recognized that many of these alternatives have advantages where facility for frequent alteration is required, but it is considered that the adequate facilities recommended make such alterations unlikely.

96. When installed in timber joist floors, conduits should be laid between and parallel to the run of the joists and be properly supported. Where it is necessary to run conduits across the joists this should be done in notches or grooves in the upper surface of the joists not more than 12 in. from the bearings.

[1] Similar cable, insulated with polyvinyl chloride, would form a satisfactory alternative to which the possibility of post-war rubber shortage gives added importance.

97. When floors of concrete or other solid material are to be used, the necessary floor ducts for the accommodation of cables and pipes should be provided during the construction of the premises.

98. When laid in wall chases, not less than $\frac{1}{2}$ in. of plaster should be allowed over the conduits to ensure that satisfactory and permanent flush surfacing is obtained.

99. As an alternative means of installing conduits, we recommend that consideration be given to the provision by the architect and builder of a continuous wall duct at skirting or at socket-outlet level, designed to accommodate the consumer's installation conduits together with the telecommunications installation. (See paragraph 129.) This duct would be provided with a detachable cover or skirting which would facilitate access for installation or alteration of socket-outlet positions. At door crossings the conduit would require to be led under the door, but in small dwellings this would present no substantial difficulty since it would be possible to plan the consumer's installation with very few door crossings. It is important to notice that, whereas the normal underfloor installation requires that the wiring shall be completed at the carcase stage of building, the provision of a continuous wall duct would enable wiring to be completed during the final stage of house fitting.

100. A new aspect, however, is given to the whole problem of wiring by the opportunities which have now been opened for co-operation with the architect in the early stages of planning. Such planning may enable proper provision to be made for cable runs and for their satisfactory concealment and correlation with the design of the building. If this co-ordination can be carried sufficiently far to enable ducts or ways to be provided throughout the building, particularly along skirtings and between floors, the flexibility of the installation and telecommunication facilities will be considerably improved and the need for conduit avoided.

101. Light twisted flexible cords are frequently a source of trouble. It is recommended that flexes of circular section should be used and that all flexes having conductors smaller than 23/·0076 in. should be discouraged. For portable appliances consideration should be given to the use of high grade tough rubber sheathed cable specially designed to give adequate flexibility.

102. A diagram showing the position of the house cable runs should be provided. This may be mounted permanently on the inner side of the door of the consumer's supply control unit.

PREFABRICATION

103. It is understood that for the construction of small houses the use of prefabricated wall sections is under consideration by various interests. In such sections the ducts or channels mentioned above should be provided as a standard arrangement in order to give flexibility of wiring.

CENTRAL HEATING

104. Some consideration has been given to the provision of central heating in flats. The energy for such installations may be supplied by off-peak electricity, but so far as the tenant is concerned, it is immaterial whether it be supplied by electricity, gas, or by other fuel. It is felt, therefore, that the general question as to whether central supplies of heat are desirable is one primarily for the Heating and Ventilation Committee, and is one in which factors conducive to smoke

abatement should be taken into consideration. If, however, central heating is adopted, it should be designed to provide background heat only and should be coupled with the use of small radiant electric fires to "top up" rooms when a higher local temperature is required.

CENTRAL HOT WATER

105. Many of the advantages of centralized hot-water supply in a block of flats can be obtained by the use of individual electric water heaters. These have the advantage that the cost to the tenant is directly proportional to the quantity of hot water used, with the result that the waste inseparable from an un-metered common supply is avoided.

C. TELECOMMUNICATIONS

GENERAL

106. Full consultation between the various interests concerned should take place at an early stage to determine:

i. The probable leading-in point of the telephone service.
ii. The best local method of receiving and distributing broadcast programmes, both sound and vision.
iii. Local restrictions, if any, on the erection of outdoor aerials.
iv. Information in regard to other low voltage services likely to be installed.
v. The extent of the proposed installation, the proposed locations of equipment, and the provision to be made to ensure the concealment of all wiring and the recessing of accessories where possible.

DOOR BELLS

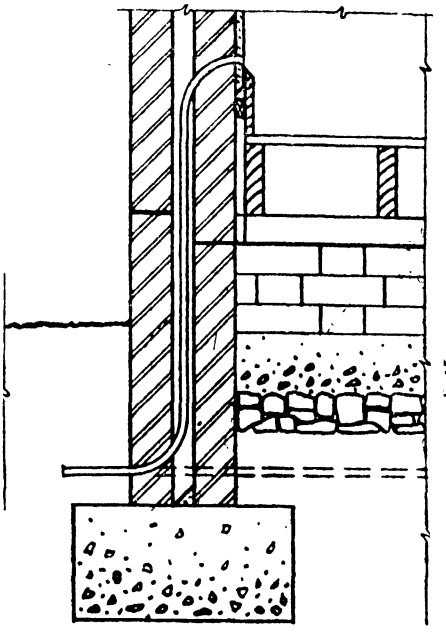
107. Door bells will be required in most dwellings. These are preferably operated from the electricity mains by means of a small transformer which may be accommodated in the consumer's supply control. The bell circuits may be run by a direct route and protected by light conduit where necessary. Alternatively, if ducts or conduits for other low voltage telecommunications are provided, the bell circuits may be run therein provided the transformer has an earthed screen or is otherwise designed to withstand a suitable test voltage between primary and secondary windings (*B.S.* 832).

TELEPHONES (CONNECTED TO THE PUBLIC SYSTEM)

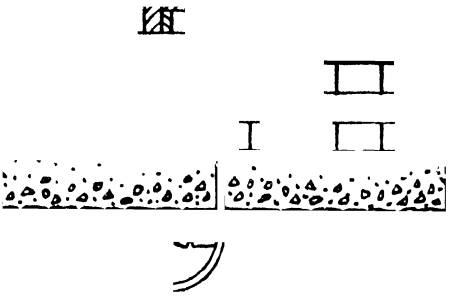
108. It is to be expected that in post-war years a telephone may be regarded as a necessity by a larger portion of the population than hitherto. In addition it should be remembered that telephones are frequently installed by public utility companies and the like in the residences of their employees. For these reasons the probability of a telephone being required in any dwelling should be envisaged.

109. Facilities will be required for leading in the service to the building from either an overhead or underground distribution system. The overhead system may be led into the building through any exterior wall according to the position of the nearest pole, but the underground system will generally be led in from the street side.

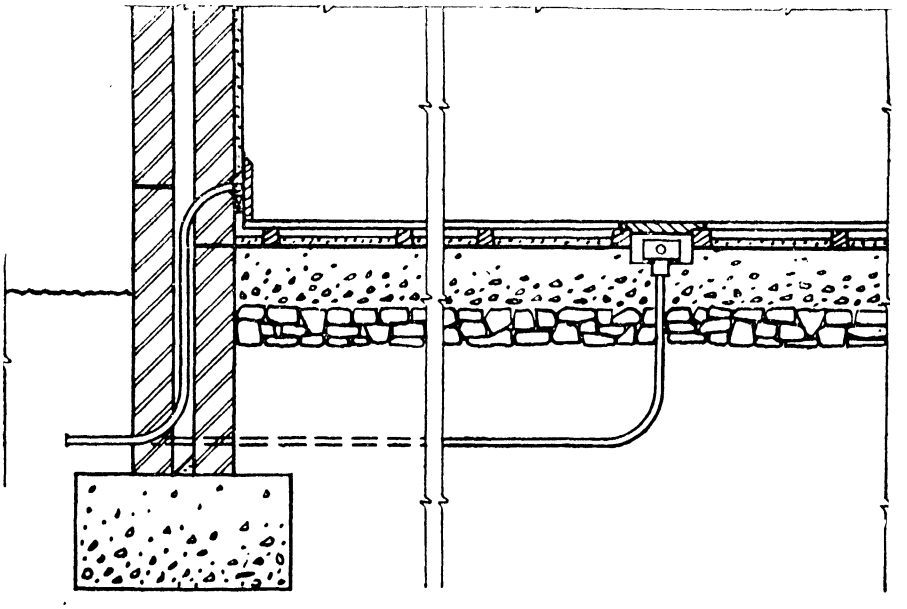
110. The normal method of terminating overhead circuits on any building is by means of various types of brackets for fixing to the walls, eaves, or chimney. A wall spike is frequently used for wall fixing. It is recommended that the telephone manager should be consulted at an early stage as to the best positions and patterns for fixtures, so that if they are required they may be fixed during building operations rather than later.



(*a*) Where no provision is made for accommodation of internal Telecommunications wiring (wood joist floor)



(*c*) Where underfloor conduits are provided for Telecommunications wiring (wood joist floor)



(*b*) Where internal Telecommunications wiring may be run in hollow skirtings (concrete floor)

(*d*) Where underfloor conduits are provided for Telecommunications wiring (concrete floor)

Fig. 5. PROVISION FOR LEADING IN TELECOMMUNICATIONS SERVICES TO DOMESTIC PREMISES (See paragraph 114)

111. The lead-in from overhead should be effected by means of a pipe of metal, porcelain, or other insulating material installed in accordance with paragraph 26. Where the interior wall construction permits, a recess should be provided approximately 6 in. by 4 in. by 3 in. deep for housing the protective device necessary on overhead circuits, and into which conduit to other parts of the premises can be led if required.

112. The lead-in from underground distribution should be effected by the provision of a pipe or conduit through the outer wall of the building and extending to a position inside the building for linking up with the internal duct system, if any. The telephone manager will give details of place of entry and size of conduit required. The pipe or conduit for an underground lead-in should be provided in all cases even should the service in the first instance be overhead. It is anticipated that a pipe of about 1-in. diameter will be adequate.

113. It is important that pipes or conduits not in use and the annular space between any sleeve or pipe and its cable should be sealed with suitable material to prevent the entry of water, gas, or vermin.

114. The position and manner of terminating the conduit will depend upon the type of internal duct system, if any. Suggested arrangements for houses having various floor and wall constructions are illustrated in Figure 5.

115. The extension of the wiring from the lead-in to the telephone instrument is discussed in paragraphs 128 and 129.

SOUND BROADCASTING

116. It is expected that reception of sound broadcasting will be required in every dwelling in the post-war period, and therefore leading-in and other facilities as described below should be provided.

117. A fixture for an outdoor aerial may be required, normally at the back of the dwelling. Any aerial fixture on the building should be near the point of entry and should be as nearly vertically above it as possible. In housing estates communal arrangements are desirable so that "forests" of masts may be avoided. The use of a common suspension wire for supporting a number of separate aerials is suggested. An efficient means of earthing the aerial should be provided.

118. A lead-in through a wall or window near the expected position of the receiver will be needed. An insulated pipe led through the wall, as described in paragraph 26, is recommended. All internal wiring connecting an outdoor aerial to a receiver should be effected in screened cable and run well away from power and lighting cables.

119. An outdoor aerial is generally more efficient, but, where this is not permissible or not desired, facilities should be provided for erecting an indoor aerial in the loft or roof space, with facilities for leading the aerial down through the walls to the receiver by means of a cable way or non-metallic duct arranged so as to be as remote from other services as conveniently possible.

120. The receiver should be near the aerial lead-in. This may influence the position of the socket-outlet required to supply the receiver.

121. An effective earth will be necessary for the receiver. A bare copper wire installed during the construction of the building and run as directly as possible, preferably to the main water pipe, or alternatively to an earth spike or plate outside the building is recommended. A gas pipe should not be used for obtaining an earth.

122. An extension loud speaker may be required. Lead covered or other screened cable will be necessary if the extension leads run in the same conduit as the telephone or other services.

WIRE BROADCASTING

123. This service is at present generally provided by overhead distribution, but after the war it may be provided by underground cable. This may be brought in by the pipe provided for the telephone service. The extension of the service lead from the lead-in to the receiver or loud-speaker is discussed in paragraph 129.

TELEVISION

124. Television service will probably develop rapidly after the war and may be used by the occupiers of most new dwellings within the lifetime of the property. The pipe proposed in paragraph 118 will serve for leading-in this service from an aerial, and that proposed in paragraphs 112 to 114 for leading-in from underground, if "wired television" is introduced.

125. Separate fixtures may be required for sound and television aerials, and it is particularly important that the television aerial should be as high and as far away as possible from "man-made" electrical disturbances.

RADIO INTERFERENCE

126. Legislation requiring the suppression of radio interference from electrical apparatus and appliances, as recommended in the Institution's Report on Electrical Interference with Broadcasting of July 1936, was contemplated before the war, and the desirability of proceeding with this legislation is emphasized.

127. In certain circumstances, there may be interference by radiation from the electricity supply installation. Where the consultation referred to in paragraph 106 indicates that there is serious probability of such interference, some form of metallic screening of the supply wiring will be necessary. The increasing use of indoor aerials and the probability of television developments gives emphasis to this point.

PROVISION FOR WIRING

128. The provisions already discussed for leading-in the various services may require the installation of three leading-in pipes, namely:

i. A pipe for leading-in from underground (*a*) the telephone service, (*b*) wire broadcasting service, and (*c*) television service. (See paragraphs 112 to 114, 123 and 124, and Figure 5.)

ii. A pipe for leading-in from overhead, either a telephone service or a wire broadcasting service or both. (See paragraphs 111, 123.)

iii. A pipe for leading-in an outdoor aerial. (See paragraph 118.)

129. Planned design should enable telephone, radio, and television services to be distributed within a building without damage to the fabric or disfigurement of the decoration. The recommendation in paragraph 99 is intended not only to cater for immediate and known requirements, but to have regard to future developments. As an alternative a deeply grooved picture rail may provide a convenient housing for the telecommunication circuits.

SECTION 2. INSTALLATIONS IN LARGER HOUSES AND FLATS

130. In the previous section we have discussed the requirements of the small houses and flats which are likely to form the major post-war building programme. In addition a substantial number of larger houses and flats will be required, namely (referring to paragraph 11) the larger houses in group (ii), the houses in group (iii), and the high rental flats in group (iv). The requirements of these larger types of dwellings may now be considered. To avoid repetition the following recommendations specify the requirements of larger premises only in so far as they differ from those of the smaller dwellings.

131. At the outset it may be noted that most larger houses and flats are likely to be individually designed. In addition, in such dwellings economic considerations will impose a less stringent limit on the electrical equipment to be installed, and on its use. Hence the electrical installations of such premises can be more ample in scope than those proposed for small dwellings.

A. SERVICE AND CONTROL ARRANGEMENTS

SERVICE TO HOUSES FROM UNDERGROUND AND OVERHEAD DISTRIBUTION SYSTEMS

132. The service to larger houses will be by means of underground or overhead cable, generally as proposed in paragraphs 15 to 26, except in respect of cable size. The cross-section of the cable will depend on the electric power requirements of the dwelling, which will reflect the preferences of the occupier and the location and accessibility of the house in relation to public services and fuel supplies. The type of service and the cross-section of the cable will be decided by the supply engineer in the light of the probable loading.

EARTHING ARRANGEMENTS

133. Earthing arrangements as indicated in paragraph 29 will be required.

CONSUMERS' SUPPLY CONTROLS

134. The principle of housing consumers' supply control equipment in a convenient and compact manner, as discussed for small dwellings in paragraphs 30 to 44, applies with equal force to larger houses and flats.

135. In many cases a consumer's supply control unit as proposed in paragraphs 34 to 37, but containing additional fuseways for further circuits and provision for additional wiring exits, would meet all requirements. The space already proposed in paragraph 35, namely, 34 in. high by 13½ in. wide by 7½ in. deep, would without difficulty house the additional fuseways necessary. For very many larger houses eight fuseways providing for eight circuits would cover all requirements, namely:

Two 5-amp. single-pole fuseways for two lighting circuits.
One 5-amp. single-pole fuseway, spare, *e.g.* for clock circuits.
Two 30-amp. single-pole fuseways for two ring circuits, supplying general socket-outlets, water heaters, kitchen and laundry equipment.
One 50-amp. single-pole fuseway for cooker circuit.
One 30-amp. single-pole fuseway for circuit for garage work bench, greenhouse heating, garden, etc.
One 30-amp. single-pole fuseway, spare, *e.g.* for water pumping, or other special purposes.
A bell transformer, when desired.

136. These fuseways as suggested might be housed in one unit. Alternatively, it may frequently be more convenient to have the same equipment housed in two separate units, one containing the supply undertaking's cable entry and main fuse, and the main switch and meter; the other, the distribution unit containing the fuses. These would be mounted together in a suitable enclosure, or alternatively, would be separated, the main fuse, switch and meter unit being located conveniently for the service cable entry, the distribution unit being located in a central position to permit of the most economical layout of the internal installation. For still larger houses the principle can be extended by having more than one distribution unit. The position of the supply control unit and distribution units, if any, should be determined in the house design stage so that suitable wall recesses may be provided during building.

137. Quarterly meters will generally be required in larger houses, and their adoption in place of prepayment meters, shown in Figures 2 and 3, will result in further space economies.

FUSING

138. Single-pole fuses of the standard cartridge type should be used (see paragraphs 80, 85-87, 94) in consumers' supply control units, and at the ring circuit outlet positions.

CIRCUIT BREAKERS

139. Consideration may be given to the use of quick-acting circuit breakers in place of the consumer's main switch, and possibly in place of circuit fuses.

B. INTERNAL INSTALLATIONS IN LARGER HOUSES AND FLATS

EXTENT OF ELECTRIFICATION

140. For the reasons given in paragraph 131, the electrical facilities to be provided in larger houses and flats are likely to be greater than those discussed for small houses and flats in Section 1. The facilities additional to those already proposed (paragraphs 45 to 71) are summarized below.

LIGHTING

141. The architect and occupier will frequently wish to take advantage of the decorative qualities of modern lighting. Thus, in addition, or as an alternative to the minimum lighting provision previously proposed (paragraphs 46 to 48), lighting in dining rooms, lounges, studies, libraries, or bedrooms may be effected by lamps in specially designed wall recesses or in wall mounted brackets, or by indirect illumination from alcoves or cornices. Tubular filament lamps may frequently be convenient for these purposes. The fluorescent lamp, which has been widely adopted for industrial lighting during the war, may be expected to make an important contribution to this field of domestic lighting. The absence of glare from this light source is likely to encourage its use for direct as well as indirect lighting; its "shadowless" character and its colour approximating to daylight will be of particular benefit in kitchens. Household cupboards, and larders, pantries, and similar locations should be provided with lighting points which may be conveniently controlled by means of automatic door switches. Lighting points may also be required at the front gate or approach to the house and in outbuildings.

GENERAL DOMESTIC PURPOSES

142. As a minimum provision, which would meet most requirements, it is recommended that one socket-outlet should be provided in every room wall space exceeding 3 ft. in length, with additional outlets in longer walls placed so that no point along the wall floor line is more than six feet from an outlet. These socket-outlets should be of the proposed standard type (paragraphs 91 to 93). From 30 to 50 of these socket-outlets would be required in a typical detached self-contained house of the larger type. In houses of this type, having regard to diversity, it is considered permissible to connect up to fifteen standard socket-outlets on one ring circuit fused at 30 amperes. In many larger houses and flats, therefore, two or three ring circuits would adequately serve the recommended minimum number of general utility socket-outlets. The ring circuits may be "looped vertically" in the house, that is, each ring may include rooms on all floors in order to simplify wiring runs.

143. If the rating of the proposed standard domestic socket-outlet is limited to 10 amperes, appliances exceeding 2 kw. in rating, for example, 3 kw. radiant fires, water heaters, wash-boilers, etc., may be connected if the ring circuit is rated accordingly, by means of 15-ampere socket-outlets. Alternatively, a special circuit may be run to a 15-ampere socket-outlet in a required location.

144. Where maximum convenience in the use of domestic appliances is desired, consideration should be given to the provision of a continuous wall duct at skirting level, generally as proposed in paragraphs 99 and 100; in this socket-outlets might be provided at intervals of, say, 6 ft. around every room.

COOKING

145. The factors already discussed (paragraph 51) indicate that electric cooking may be expected to have a wide application in larger dwellings also. For the majority of the larger dwellings under consideration a cooker for 7 to 10 persons, having a rating of approximately $8\frac{1}{2}$ kw., will usually be regarded as ample. The space required for larger domestic cookers is referred to later. (See paragraphs 174 to 177, and Figure 6.)

146. An electrically heated food trolley may be required. For its convenient use a "loading bay" and socket-outlet near to the cooker position should be arranged when planning the kitchen.

WATER HEATING

147. The proposals made for water heating in small houses (paragraphs 56 to 61) apply generally to larger houses and flats. The desirable size of water heater to give a satisfactory supply depends on the size of household under consideration, and on whether a solid fuel water-heating system is also to be provided. In the latter case, provided the hot-water system is suitably designed, a thermostatically controlled immersion heater of suitable rating can be fitted in the hot-water storage tank for "topping up" and for summer use. Alternatively, an electric water heater of suitable capacity fitted with two heater-thermostat units may be coupled to the solid fuel boiler instead of the usual hot-water storage tank. A small water heater in the kitchen to provide an independent source of hot water may be desirable in addition, and provision may be made for the accommodation of this convenient to the sinks. Ratings and dimensions of typical water heaters of various types and capacities are given in Section 3 on electrical domestic appliances. (See paragraphs 186, 187, and Figures 9 and 10.)

REFRIGERATION

148. The refrigerator of 4 cu. ft. capacity already proposed for use in smaller dwellings may also adequately meet the requirements in some larger dwellings. Kitchen planning should make provision for building the refrigerator into the cupboard accommodation at a suitable position. The dimensions of the proposed 4 cu. ft. model are given in paragraphs 178 and 179, and Figure 7.

OTHER ELECTRICAL REQUIREMENTS IN THE KITCHENS OF LARGER HOUSES OR FLATS

149. A mixing machine is likely to become a usual requirement, and space for storing and for using this conveniently should be provided. The appliance will be supplied from a convenient socket-outlet.

150. A dish-washing machine may be required, and consideration may be given to the space requirements of this appliance when designing the kitchen sink arrangements.

SPACE HEATING AND VENTILATION

151. With a view to effecting economy in heating throughout the life of a building the architect in consultation with the owner should give early consideration to the thermal insulation characteristics of a dwelling. This matter and the entire problem of space heating are dealt with in the Report of the Heating and Ventilation Committee. It may be noted here that in addition to savings which can be effected by structural means, such as cavity walls and boarded and felted lofts, further economies may be obtained by using on room walls thermal insulating finishes which rapidly attain "comfort" temperatures when radiantly heated. Thus, in comparison with plaster surfaces, wood panelled walls or walls covered with a thick paper substantially reduce the heating necessary to attain comfort conditions.

152. The proportion in which electricity is used for space heating will be determined on grounds of convenience and cleanliness, and of relative cost and availability of electricity and its alternatives.

153. Heating may be provided electrically by means of radiant electric fires or convectors usually of ratings of 1 or 2 kw. In larger rooms ratings of 3 kw. or more may be desirable. Radiant electric fires are particularly suitable for intermittent heating, or for "topping up" general heating provided by other means. The proposed positions of such fires should be carefully considered, especially if they are to be of inset types, since these may limit the arrangement of furniture. In bathrooms, cord switch operated wall mounting radiant electric fires should be used exclusively. Alternatively, when continuous warmth is to be maintained, convection heating may be effected by means of thermostatically controlled convector units, by tubular heaters at skirting level, or by heated skirting panels or wall or ceiling panels. The locations of inset radiant fires or convectors should be agreed at an early stage so that suitable recesses may be provided when building. The recommendations of paragraphs 184 and 185 should also be observed.

154. With regard to ventilation, when special provision for this is desired suitable fans or fan heaters built into outside walls may be used to draw in fresh air and if necessary to warm it. Conversely, it may sometimes be desirable—as, for example, in doctors' waiting rooms or in kitchens—to provide air-extracting fans. In either case suitable provision should be made for incorporating the fan

unit in the wall or window. In blocks of higher rental flats and in noisy situations, trunked ventilation controlled by suitable louvres may be adopted in suitable cases.

LAUNDERING

155. Although outside laundry services may be widely used by the residents of larger dwellings, we consider that a separate laundry or "utility room" adjacent to the kitchen would be advantageous in larger houses. This should be designed to enable all laundering to be done quickly, conveniently, and with minimum effort. Electrical appliances are available for boiling, washing, rinsing, wringing, or centrifugally drying, and for pressing and ironing. As one machine may combine two or more of these functions it is not possible to give precise guidance regarding space requirements and layout. A hot-water supply, either from the main domestic hot-water system or from an electric water heater provided for the purpose, is also necessary. To give full convenience it is recommended that provision should be made for four socket-outlets in the "utility room," one of which should be of 15-ampere capacity. These may be included on one of the house ring mains, or alternatively, may be fed from a special laundry circuit run from the consumer's supply control. The heavier appliances, alternatively, may be connected permanently to wall connector boxes by means of flexible cable enclosed in flexible steel tubing. Care must be taken to ensure satisfactory permanent earthing of the laundry appliances.

156. A properly designed drying cupboard, as recommended in paragraph 71, should form an integral part of the utility room.

157. In higher rental flats it is assumed that outside laundry services will be the general choice. Although the "utility room" proposed above for houses will therefore not generally be necessary, an electrically heated drying cupboard should be provided. Apart from its value in drying "smalls," it may be used for drying wet outdoor clothes, and for providing continuous drying facilities for a baby's requirements which otherwise present a major inconvenience in a flat.

CLOCKS

158. An electric clock in the kitchen is particularly desirable, and clock connector points may also be required at one or more of the principal mantelshelves or other convenient positions. A special house circuit may be run for clocks, but where this is not justifiable, clocks should preferably be connected to the lighting circuit.

OTHER ELECTRICAL REQUIREMENTS OF THE LARGER HOUSE

159. Consideration should be given to the lighting and power requirements of the following:

Garage. A roof light, and possibly an entry light and local bench light, will be required. Several standard socket-outlets should be provided for a hand lamp, for general or anti-frost heating, electric soldering, small motor-driven tools, car oil filter, etc.

Workshop. Provision generally as for the garage may be required.

Greenhouse. Lighting and outdoor protected type socket-outlets or connecting boxes may be required for tubular heaters, convectors, humidifiers, pumps, water heaters, soil heating, liquid culture tank heating, and the like.

Garden. Outdoor protected type socket-outlets may be required for electrically heated frames, utility or ornamental lighting, small fountain pumps, motor mowers, etc.

Water Supply. Houses will generally be built where a public water supply is available, but choice of site need not be restricted in this way, since an electric pumping pressure tank system can give an equivalent water service from any convenient suitable water source.

SYSTEMS OF WIRING, POSITION OF LIGHT SWITCHES AND SOCKET-OUTLETS, ETC.

160. The recommendations contained in paragraphs 73 to 102 apply also to larger houses and flats.

C. TELECOMMUNICATIONS IN LARGER HOUSES AND FLATS

161. The provision for telephones, and for sound and television broadcasting recommended in paragraphs 106 to 129, apply with added force to larger houses and flats, and consideration should be given to the installation facilities to be provided for all telecommunications services.

162. Ideally it should be possible to run cables from any position in a house to any other position through ducts or chases concealed in the fabric, but it is realized that the achievement of this ideal is not a practical possibility in the majority of buildings. The provision made for wiring in any house or flat will depend upon the general standard of amenities desired and upon the permissible expenditure. As a guide to architects and others concerned, the following suggestions are arranged in descending order of efficiency:

i. The most flexible and most generally available provision for wiring would be effected by the construction of a duct or chase behind detachable skirtings in all rooms, halls, and passages.
ii. Conduits generally as proposed in paragraph 99.
iii. Deeply grooved picture rails associated with connecting tubes.

OTHER TELECOMMUNICATION INSTALLATIONS

163. Other facilities as described below may be required according to the size and occupancy of dwellings. The actual requirements of these and other miscellaneous services should be ascertained during the planning of the building, and due provision made.

DOOR BELLS

164. A front door bell will be needed in most dwellings and in many cases internal bell systems will also be required. The bell should be mounted in the kitchen together with a room indicator when this is required. The bell transformer and low voltage wiring should be provided in accordance with the recommendations contained in paragraph 107.

HOUSE TELEPHONES

165. A house telephone system may be required in the largest type of house, and in addition to the provision for wiring already discussed, accommodation will be required for junction boxes, connecting rosettes, and batteries. There are several types of installation available, but their physical characteristics do not differ appreciably.

FIRE ALARMS

166. A fire alarm system may be required in certain premises. Numerous systems controlled by press buttons and/or thermostats are available and may

be operated from the electric supply mains or by means of batteries. In all cases bells will be required where they can be heard throughout the building, and it may be desirable to give, in addition, an indication of the site of the alarm or fire.

BURGLAR ALARMS

167. Burglar alarms may be required in certain circumstances. Here again several types of equipment are available, and concealed accommodation will be required for certain apparatus, batteries, and wiring.

CONTROL POINT OF HOUSEHOLD TELECOMMUNICATIONS INSTALLATION

168. The telecommunications services required may include a telephone and one or more extensions, wire broadcasting and television services, and low-frequency distribution from the radio receiver to loud-speakers in other rooms. For the convenient distribution of these services a number of terminal blocks and connection strips may be required. To avoid surface mounting of these items, possibly in several places, it is proposed that at a convenient central position a covered recess of approximately 9 in. by 12 in. by 3 in. deep should be provided for their accommodation. This would become the control and distribution point of the household telecommunications installation.

SEGREGATION OF WIRING

169. Separate conduits segregating the telecommunications services from the electricity power installation may be required if the conditions of high voltage referred to in Regulation 903 of the Wiring Regulations occur. In addition, the Post Office telecommunications wires should not be run in the same conduit as:

i. High signal-level circuits used for relaying broadcast programmes.
ii. Wires associated with fire alarms, burglar alarms, clocks, bells, or other devices operated from the electricity supply mains unless the supply from the mains is derived in a manner approved by the Post Office.

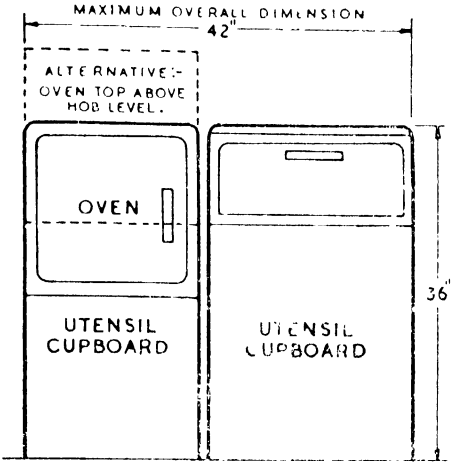
RADIO INTERFERENCE

170. A consideration additional to those already discussed in paragraphs 126 and 127 arises in relation to doctors' and dentists' premises. In these, high-frequency apparatus such as electro-medical apparatus of the diathermy type may be used, and an adequately screened room should be provided for their accommodation. Suitable methods of screening are described in the Post Office Engineering Instruction on Radio Interference. (Post Office Reference: Radio Interference C1101.) Under S.R. & O. 1940, No. 1644, such apparatus may be used only under the authority of a permit granted by the Postmaster-General, and a condition of the permit is that the apparatus shall only be used in a screened enclosure.

SECTION 3. ELECTRICAL DOMESTIC APPLIANCES

A. GENERAL

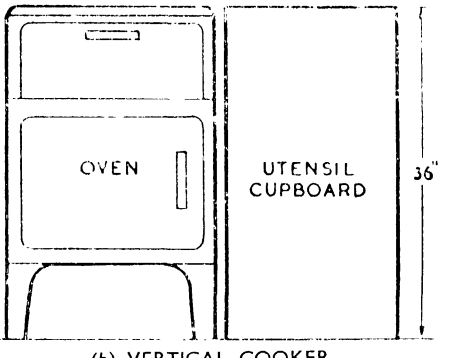
171. The use of electrical domestic appliances was becoming universal in pre-war years. Many appliances were already regarded practically as essentials. Increasing use of appliances may be expected in the post-war period both in view of the home amenities that electricity can provide, and in view of the emphasis that is likely to be placed on domestic labour saving.



(*a*) HORIZONTAL COOKER

Provisional Overall Dimensions:

Grill Boiler Unit	22″ wide, 21″ deep, 10–12″ high
Oven	18″ wide, 21″ deep, 18½–20″ high



(*b*) VERTICAL COOKER

Grill Boiler and Oven with:	Overall Dimensions* Height†	Depth	Width	Kw.
One Boiling Plate	42″	24″	24″	6
Two Boiling Plates	43″	25″	29″	8½
Three Boiling Plates	44″	26″	30″	11

Fig. 6. ARRANGEMENT OF HORIZONTAL AND VERTICAL COOKERS with utensil cupboards, showing relative utilization of kitchen space. The dead space under the vertical cooker is effectively used in the horizontal arrangement

(See paragraph 176)

* These are maximum external dimensions. Smaller sizes in each group occupy smaller space (up to 3″ to 4″ smaller in width and depth).

† Including splash plate which is not shown.

172. An indication of the wide variety of uses of electricity may be gained from the following list of some appliances available in pre-war years:

Car engine heaters.
Clocks.
Cookers.
Dish-washers.
Fans.
Fires—convectors,
fan heaters,
panel heaters,
radiant electric fires,
tubular heaters.
Food trolleys.
Food warming plates.
Garage and workshop tools.
Hair driers.
Heated aquariums.
Immersion heaters.
Irons.
Kettles.
Mixing machines.
Motor lawn mowers.
Percolators.
Polishers.
Pump motors.
Radio receivers.
Razors.
Refrigerators.
Sewing machines.
Soldering irons.
Television receivers.
Toasters.
Ultra violet and other electro-medical appliances.
Vacuum cleaners.
Wash-boilers.
Washing machines.
Water heaters.
Wringers.
Etc.

173. In the following paragraphs dimensional details are given of the larger appliances for which due provision should be made in designing and building dwellings. Attention has been given to the generally expressed view that a kitchen "working top height" of 36 in. is likely to be most convenient for the average woman.

B. COOKERS

(Also see paragraphs 51 to 55 and 145 to 146)

174. In reaching decisions on the type of cooker for use in post-war housing we have been guided by the views expressed by the women of the country through their various organizations. The main features for which preference has been expressed may be summarized as follows:

i. An oven at table height, involving a "horizontal" arrangement of the grill-boiling hob and the oven.
ii. A quick heating oven.
iii. Thermostatic control of oven temperature.
iv. Ample grilling space.
v. At least one boiling plate, in addition to the grill boiler.
vi. Simmering control of boiling plate.
vii. Greatest possible ease in cleaning.

175. We therefore recommend that in post-war houses and flats provision should be made in planning the kitchen for the use of "horizontal" cookers incorporating these features. For small houses and flats a cooker arranged as in Figure 6 (*a*) is proposed. The width (wall space) permitted for the cooker is 42 in. Its depth from back to front is 20 in. The heights of the hob and of the oven are yet to be decided but will be of the order of 10 to 12 in. and 18½ to 20 in. respectively.

176. The cooker manufacturers who are members of the British Electrical and Allied Manufacturers Association have collaborated in preparing designs of the proposed "horizontal" cooker, but wish to emphasize that the economic production of a new design is only possible provided the article is made in sufficient

quantities. For this reason it is essential that the design of post-war kitchens should be such as to allow adequate space for "horizontal" cookers. It may be noted that although the "horizontal" cooker takes up a greater width it utilizes to better advantage the kitchen space which must in any case be devoted to the cooker and utensils, since the space below becomes useful cupboard space. See Figures 6 (*a*) and (*b*).

177. "Vertical" cookers generally in accordance with existing types will continue to be available, and new models incorporating all the features (ii) to (vii) will also be produced. Overall dimensions are given in Figure 6 (*b*).

C. REFRIGERATORS

(Also see paragraphs 62, 63 and 145)

178. Having regard to the considerations of paragraphs 62 and 63, and in consultation with the Domestic Electric Refrigeration Association, we have reached the conclusion that the advantages of refrigeration may best be obtained from a unit incorporating the following features:

i. Adequate storage capacity.

ii. Low running costs.

iii. Fully automatic and interchangeable air-cooled unit.

iv. Ice-making facilities.

v. Ample shelf accommodation.

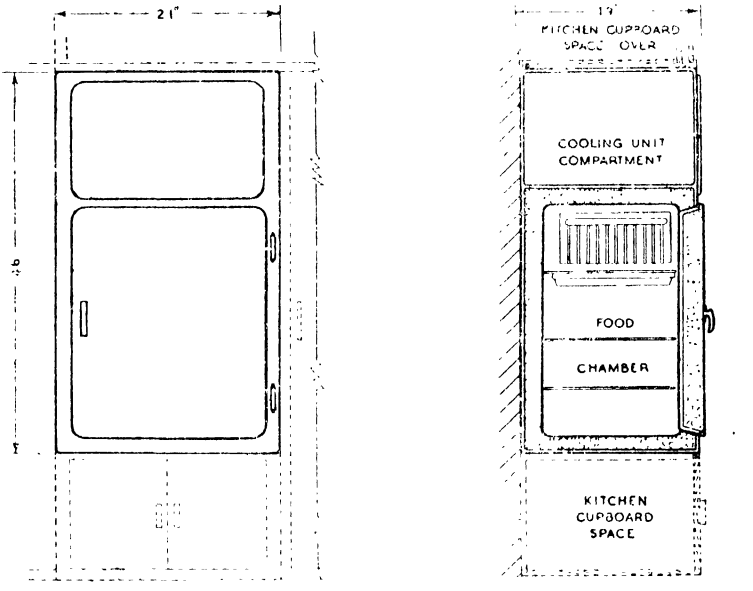


Fig. 7. REFRIGERATOR OF 4 CU. FT. CAPACITY
Shown built in as a kitchen fitment at service height with cupboard space above and below (See paragraphs 62 and 179)

179. A storage capacity of 4 cu. ft. is recommended as being the minimum size adequate for the accommodation of perishable foodstuffs in a normal household. The overall dimensions of a refrigerator of this capacity, as shown in Figure 7, are 21 in. wide by 19 in. deep by approximately 46 in. high. The unit is designed for "building-in" as a kitchen fitment at service height with cupboard space above and below, thus effecting the utmost economy in floor space.

D. WASH-BOILERS AND WASHING MACHINES

(Also see paragraphs 67 to 71 and 155 to 157)

WASH-BOILERS

180. Electric wash-boilers of round and square patterns generally in accordance with existing types will be available. Boilers of the round pattern have a capacity of 10 gallons. Their maximum overall dimensions are 29 in. high by 19½ in. in diameter. Square boilers have approximately the same overall dimensions.

WASHING MACHINES

181. Having regard to the recommendation contained in paragraph 67, it is proposed that for use in small houses and flats a washing machine generally as shown in Figure 8 should be available. The manufacturers of washing machines have collaborated in preparing this design, but it is emphasized that its economic production will only be possible if sufficient numbers are to be manufactured. The machine incorporates a power-driven washing device and wringer. The latter is stored in the body of the machine when not in use. The capacity of the bowl is approximately 10 gallons to the load line (when not charged with washing). The machine is 22½ in. square in section and is mounted on castors for mobility. Its overall height when the wringer is removed will be designed in relation to the proposed standard height (36 in.) of the kitchen sink, so that when in use the wringer may be swung over the sink. When not in use, the machine may be conveniently stored under the draining board adjacent to the sink, or in an alternative position for which space provision should be made when designing the kitchen.

182. Washing machines generally in accordance with pre-war types will remain available.

E. RADIANT ELECTRIC FIRES AND ELECTRIC CONVECTORS

(Also see paragraphs 64 to 66 and 151 to 153)

183. Various types of radiant electric fires and electric convectors generally in accordance with pre-war practice will be available.

184. It is recommended that the dimensions of these appliances should be correlated to the proposed standard openings of solid fuel fire-places so that, when desired, they may be placed in solid fuel fire-places to form a unified and pleasing arrangement.

185. The design of inset radiant electric fires and electric convectors should be such as will minimize the tendency of convection air currents to discolour wall finishes. Also when installing such appliances a backing of asbestos or other heat-insulating material should be provided to minimize heat loss through the wall.

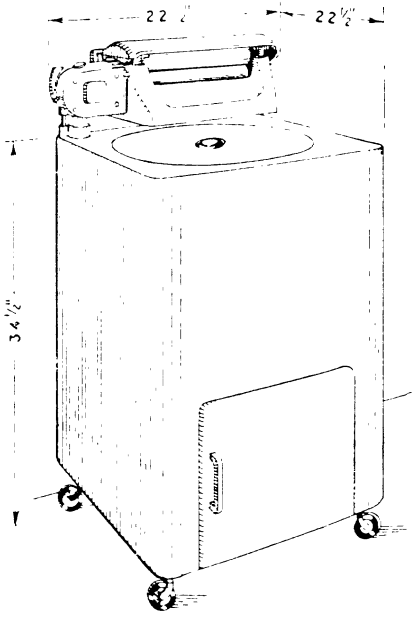


Fig. 8. ELECTRIC WASHING MACHINE

When in use the wringer may be swung over a 36" sink. When not in use the wringer is stored in the base of the machine. The overall dimensions given are approximate. (See paragraphs 67 and 181)

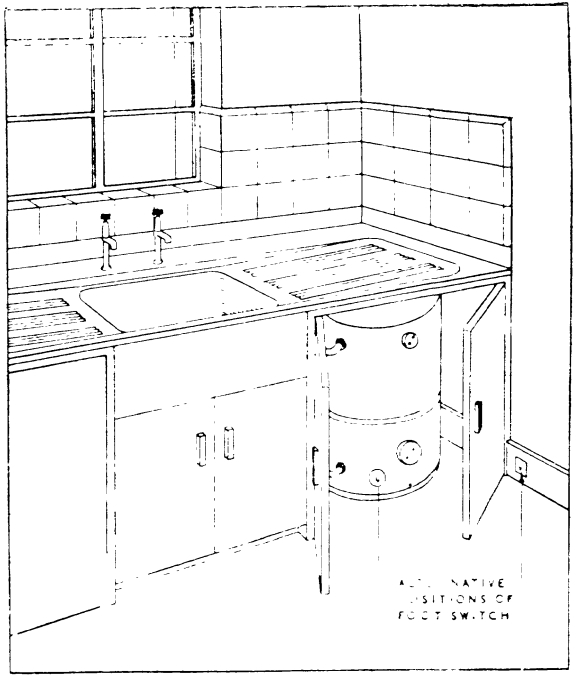


Fig. 9. WATER HEATER HOUSED UNDER SINK DRAINING BOARD

Approximate overall dimensions of lagged tank (20 gallons) 33" high × 20" diameter
(See paragraphs 59 and 187)

F. WATER HEATERS AND IMMERSION HEATERS

(Also see paragraphs 56 to 61)

ELECTRIC WATER HEATERS

186. Electric storage water heaters of the types described in paragraph 56 are made in various sizes from 1½- to 30-gallon capacity. The capacities, ratings, and overall dimensions of various types and sizes are given in Figure 10.

187. The type of water heater (to which reference has been made in paragraph 59) which is designed to store, for immediate use, a small quantity (of about 6–7 gallons) of hot water without heating the entire contents of the tank, will also be available. The approximate overall dimensions of a lagged storage heater of this type of 20 gallons capacity are 33 in. high by 20 in. in diameter. A suggested arrangement of such a heater under a sink draining board is shown in Figure 9.

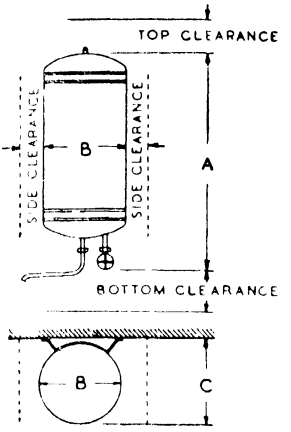
IMMERSION HEATERS AND THERMOSTATS

188. In paragraph 60 the recommendation is made that all solid fuel fired hot-water storage tanks should be bossed for the insertion of an immersion heater thermostat unit at the most effective position. If effect can be given to this recommendation the manufacturers will produce a standard range of heater-thermostat units for the purpose. At present immersion heaters with or without associated thermostats are available in 1, 1½, 2, 2½, and 3 kw. ratings, and have lengths in some types up to 42 in.

G. STANDARDS OF SPACE HEATING AND WATER HEATING

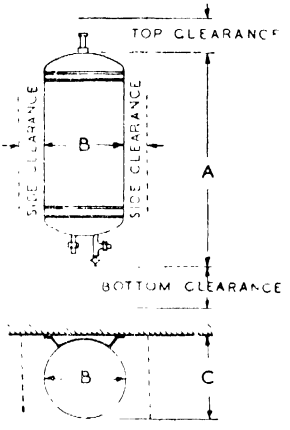
189. We consider that the arrangements we have proposed are adequate to provide space and water heating in accordance with the standards recommended in the Report of the Heating and Ventilation Committee. The only point of difference worthy of note is that whereas the Heating and Ventilation Committee recommend that the water-heating installation should be capable of supplying 250 gallons per week at 140° F., we recommend that a correspondingly lesser quantity of water (210 gallons) should be provided at a higher temperature, 160° F., the net energy consumption being identical in each case.

190. We are considering the preparation of a supplementary report dealing in detail with space and water-heating proposals, capital, and running costs, etc., and do not propose to discuss these matters in the present document.



CAPACITY (GALS.)	KW.	DIMENSIONS (INCHES)		
		A	B	C
1·5	[illegible]	26·75	11	11·5
3	1·0	35	13	13·5
5	1·0	38·5	14	14·75
12	1·5	47·25	18	18·75
15	1·5	57·5	18·5	19·25
20	2·0	59·5	20·5	21·25

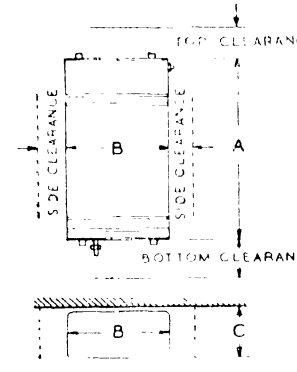
(*a*) Open-outlet non-pressure type



CAPACITY (GALS.)	KW.	DIMENSIONS (INCHES)		
		A	B	C
12	1·5	46·25	18	18·75
15	1·5	56·75	18·5	19·25
20	2·0	58·75	20·5	21·25
30	3·0	61	24	24·75

The 20- and 30-gallon sizes are also made with legs for floor-mounting. The dimensions of this type are similar.

(*b*) Pressure type, cold supply from separate cistern



CAPACITY (GALS.)	KW.	DIMENSIONS (INCHES)					
		RECTANGULAR PATTERN			ROUND PATTERN		
		A	B	C	A	B	C
5	1·0	36·5	20	12	36	15	15·75
12	1·5	41·75	26	14·5	48	18	18·75
15	1·5	41·75	30·5	15	58	19·5	20·25
20	2·0	41·75	30·5	17·5	57·25	22	22·75
30	3·0	45·5	37	19·5	68	24	24·75

(*c*) Combined cistern type

Side clearance, 6″.
Top clearance, 6″ to 9″, according to type and size.
Bottom clearance, 12″ to 24″, according to type and size.

Fig. 10. ELECTRIC WATER HEATERS

(See paragraphs 56, 57, and 186)

PART II. OWNERSHIP AND CONTROL OF ELECTRICITY SERVICE CABLES IN BLOCKS OF FLATS AND IN OTHER MULTI-OCCUPIER BUILDINGS

191. The problem of ownership and control of service cables in blocks of flats and in other multi-consumer buildings has been examined in detail. Having regard to its importance, it is thought desirable to state the considerations involved and the conclusions reached on this matter before proceeding to discuss the technical requirements of installation in such buildings. Our examination has been directed primarily to blocks of flats, but similar considerations apply to other multi-consumer buildings.

192. In the past certain practices have often restricted the use of electricity in flats, and hindered due development with consequent disadvantage to the consumer. Basically the problem of supplying electricity to flats differs from that of supplying electricity to houses only in that the service cables are installed vertically and horizontally within buildings instead of being laid in streets. Considered as a technical problem, supplying a block of flats is in fact simpler and usually less expensive than supplying an equal number of houses.

193. In practice, however, supplying houses is simpler, as the supply undertaking usually owns and installs the service cable up to the consumer's terminals, whereas in flats the building owner often supplies and owns the service cables from the undertaking's service point, just within the property boundary, up to each consumer's terminals. In such instances the capital charges on the service cables are necessarily included in the rents of the flats, and thus consumers in flats pay relatively more in the aggregate for electricity supply than consumers in houses. In certain cases the landlord has taken a bulk supply and acted as a retailing intermediary between the undertaking and the consumer, a practice which we strongly deprecate as being open to abuse and not in the best interest of the consumer.

194. In considering this whole matter we have regarded the statutory obligation of undertakings to maintain the voltage at the eventual consumer's supply terminals as a basic consideration, and have reached the conclusion that this obligation can be satisfactorily discharged only when the undertaking approves the minimum capacity of the service cables and has control over them.

195. This condition is automatically obtained in a large number of blocks of flats in which, by arrangement, the undertaking installs and owns the service cables, but in cases in which the service cables are supplied and owned by the property owners, the supply undertaking's control should still extend to the eventual consumer's terminals. It is recommended that in the best interest of the consumer the supply undertaking should in all cases own the vertical and horizontal service cables up to the eventual consumer's terminals, and pay as much towards the cost of these cables as they normally do for equivalent service cables to houses. This recommended practice is already accepted and adopted in parts of London, and in certain other parts of the country including parts of Scotland.

196. The maintenance of the cables and the possibility of the necessity arising for an increase in their capacity, or alteration in their position unforeseen at the time of installation, should be governed by an arrangement between the property owner and the supply undertaking on similar lines to that under which the original cables are provided.

SERVICE CABLES IN FLATS

197. In many instances the installation contractor responsible for the general installation work also installs the vertical and horizontal service cables. It is not intended that this practice should be affected by the foregoing proposals but only that the cost, or part of the cost, of the work should be borne by the supply undertaking.

ARCHITECTURAL PROVISION FOR SERVICE INTAKE AND CABLES

198. In the past there has frequently been an insufficient appreciation of the importance of making suitable provision in the structure for electricity service. Suitable space has often not been allowed for central service arrangements, which may include a transformer substation, and proper facilities have not always been provided for the vertical and horizontal service cables. This, in addition to the difficulties associated with ownership, has frequently resulted in piecemeal development in which installations have been carried out without any properly conceived scheme of dealing with ultimate requirements, the wiring having to be added to from time to time to meet applications for supply, causing unnecessary expense and general dissatisfaction to consumers.

199. The adoption of the proposal that the supply undertaking should in all circumstances specify and control the service cables would substantially reduce these difficulties in future.

RECOMMENDATIONS

200. Summarizing the preceding considerations and having regard to the technical and practical problems involved, we make the following recommendations which are designed to facilitate and to reduce the cost of providing electricity supply to large blocks of flats, it being the intention that all tenants should be direct consumers of the supply undertaking:

i. Those responsible for the design and planning of a building should confer at an early stage with the electricity supply and telecommunications undertakings concerned, to ensure that suitable provision shall be made for the accommodation of these services.

ii. Adequate vertical and horizontal service cables should be incorporated in all multi-consumer buildings when erected so as to ensure that the tenants are free to make full use of electricity.

iii. The supply undertaking should specify the minimum sizes of the service cables, a suitable agreement being made where necessary between the supply undertaking and the building owner.

iv. The ultimate ownership and control of the service cables should be vested in the supply undertaking, who would be responsible for maintaining them and for arranging for their capacity to be increased when necessary, or for any alteration necessitated by alterations to the building.

v. The supply undertaking should bear the whole or part of the cost of the service cables in the same way as they would normally do for service cables to equivalent houses.

201. The foregoing recommendations are applicable to multi-consumer premises in general.

PART III. ELECTRICITY IN MULTI-OCCUPIER AND SIMILAR BUILDINGS: BLOCKS OF FLATS, OFFICES AND ADMINISTRATIVE BUILDINGS, DEPARTMENT STORES AND HOTELS

202. In Part I recommendations are made regarding the electrical facilities to be provided within individual flats. Recommendations regarding the provision of service cables within blocks of flats and other multi-occupier buildings and their ownership and control are made in Part II. The technical requirements of installations in blocks of flats and in offices and administrative buildings, department stores and hotels are now discussed.

203. An advance should be made in the provision of electrical convenience and facilities in these buildings, and in particular in offices and administrative buildings, many of which at present possess inadequate installations, frequently associated with gloomy and unhealthy working conditions. Hotels also are frequently gloomy and cold and fail to provide that contrast to our winter climate which would be welcomed by, and would encourage, foreign visitors. We would also in this connection refer to railway stations, which, even in normal times, were frequently gloomy and depressing. The potentialities of electricity to eliminate such conditions in future buildings by means of good and cheerful lighting and by adequate facilities should be realized, and installations planned accordingly.

204. Although a high standard of efficiency has been attained in recent years in installation practice in new buildings, a great deal of cutting away and making good has frequently been necessary, surface wiring has been employed for extensions and alterations, and sometimes insufficient provision has been made for expansion.

205. Co-operation and collaboration, as advocated in the Introduction, are essential to avoid similar shortcomings in the future and to provide satisfactorily for adequate electrical and telecommunications installations.

206. The installation arrangements decided upon in any given case in respect of power supply and telecommunications should make provision for the following:

i. Known demands, having regard to the requirements of the owner or occupiers.
ii. Probable future demands.

207. A system of vertical and horizontal distribution and of wiring such as to facilitate expansion and extensions for existing or new purposes, changes of function associated with changes of tenancy, etc. without exceeding the capacity of ducts, and without resorting to surface wiring and cutting away, will normally prove the most satisfactory means of meeting these requirements.

208. The final plans, prior to commencement of work, should show the provisions to be made for all services.

BLOCKS OF FLATS

209. In Part I recommendations are made regarding the internal installations within individual flats. In Part II the ownership and control of service cables in blocks of flats were considered. The following Sections 1 and 2 discuss the methods of bringing electricity service cables up to individual flats. Section 6 (*a*) deals with telecommunications installations in blocks of flats.

MULTI-OCCUPIER BUILDINGS

OFFICES AND ADMINISTRATIVE BUILDINGS, DEPARTMENT STORES, AND HOTELS

210. Electrical installations in these buildings present many problems in common with those of blocks of flats. They are, therefore, discussed together in Section 1. Special requirements of such buildings are discussed in Sections 3, 4, and 5. Telecommunications installations in these buildings are discussed in Section 6 (b).

SECTION 1. COMMON REQUIREMENTS OF INSTALLATIONS IN MULTI-OCCUPIER AND SIMILAR BUILDINGS

ELECTRICITY SUPPLY INTAKE

211. In any new building, provision should be made for a 3-phase, 4-wire 400/230 volt A.C. electricity service derived either directly from an external system of low-tension mains, or from a transformer installed in the basement or elsewhere in the building, which takes its supply from external underground or overhead high-tension mains. Adequate and suitable space should be provided for a transformer substation chamber when required and for a switch and meter room, and for convenient access thereto. The dimensions of the space required will depend upon the load requirements of the building, and can only be estimated and provided for as a result of early collaboration. Detailed guidance on this matter is given in Appendix B, "Electrical Substations and Transformer Chambers" in *B.S.* Code of Practice: "The Provision of Engineering and Utility Services in Buildings" (*B.S.* 1043–1942).

COMMON SERVICES

212. Accommodation may be required for electro-mechanical equipment for lifts, air-conditioning and ventilation plant, electrode boilers and associated pumps and fuel handling equipment, for deep well or booster pumps, for kitchen and canteen or restaurant equipment, etc. Recommendations for these installations will be found in the Report of the Mechanical Installations Committee (No. 9 in this series).

VERTICAL DUCTS OR CHASES FOR RISING CONDUCTORS

213. We recommend that in all cases rising conductors should be run in readily accessible ducts or chases designed and reserved for the purpose and not used for other services, although they may form separate enclosed compartments of larger ducts provided for services in general.

214. Facilities for using electricity are required in all parts of a building. For relatively small buildings one vertical duct or chase may conveniently supply the horizontal distribution system on each floor. For large buildings, however, a single duct or chase may cause a concentration of the system undesirable for reasons of fire risk, apart from difficulties due to the sizes of the vertical and horizontal mains and the space required to accommodate them. These considerations may make it desirable to use one vertical duct or chase to serve each section or wing of a building, the horizontal distribution of the mains to each vertical duct being effected at the level of the intake or transformer chamber. The number of vertical ducts or chases required will be dependent on the type, purpose, and equipment of the building; usually one per 5000 sq. ft. of ground floor area will be necessary.

215. In general, vertical ducts or chases should not be less than 36 in. by 9 in. in cross-section, but in small premises or subdivisions of premises, smaller ducts or chases may prove adequate. In no case, however, should ducts or chases smaller than 18 in. by 6 in. be provided. The vertical ducts or chases should be associated with distribution boards provided with convenient access doors on each storey. In all cases, and in accordance with existing practice, it is necessary for fire precaution purposes to ensure that the riser does not provide a channel by which fire may be transmitted.

RISING CONDUCTORS

216. The rising conductors installed in vertical ducts or chases may be cables or bare solid or tubular conductors, the choice of system being influenced by the magnitude of the load and the flexibility required. The bare conductor system is recommended for general use, as its convenience is greater, connections or alterations to connections at the various storeys being more readily made. In addition, post-war shortage of rubber may favour this system, which makes use of other insulating materials, *e.g.* porcelain. It should be realized that the use of bare conductors absolutely precludes the running of any other service in the duct, unless the conductors are totally enclosed in trunking or partitioning so designed as to prevent accidental contact by workmen attending to other services.

LIFT SHAFTS

217. Lift shafts should not be used for the accommodation of rising conductors.

HORIZONTAL RUNS IN CORRIDORS

218. In buildings with corridors and particularly those designed for many consumers each requiring individual supply, cables or conduits may be run in floor ducts or in hollow corridor ceilings provided with detachable panels for easy access. In certain cases ring circuits may be suitable.

HORIZONTAL INSTALLATION TO PERMANENT OUTLET POSITIONS

219. Having reviewed the various methods of providing the horizontal installations to permanent outlet positions we recommend the use of vulcanized rubber-insulated[1] cable run in screwed or lug-grip-jointed welded or brazed steel conduit, placed in the floor either on the shuttering or in screeding of suitable depth, or between floor blocks. In considering the screeding it should be noted that a depth of $1\frac{1}{2}$ in. is commonly required for conduits and the screeding should be sufficiently thick to allow for this. Where conduits are placed over the shuttering, care should be taken to avoid the reinforcement rods in the bottom of the slab. All conduit runs should be fitted with convenient draw boxes which must be accessible either from the floor or from the ceiling, so that wiring or re-wiring may be conveniently done at any time.

HORIZONTAL INSTALLATION FOR FLEXIBLE OUTLET POSITIONS

220. In offices and stores, flexibility of the electricity supply and telecommunications installations on the working floors may be of paramount importance. The provision of a hollow floor such as is obtained by laying wood flooring on 3-in. bearers on the main floor structure possesses great advantages from this point of view. In such a floor a comprehensive conduit grid system serving socket-outlets on walls, stanchions, and in floor boxes may be provided, and in addition sprinkler pipes, cash delivery tubes, and other services may be accom-

[1] Similar cable insulated with polyvinyl chloride would form a satisfactory alternative to which the possibility of post-war rubber shortage gives added importance.

modated. If post-war timber shortage renders the construction of such floors difficult, it is hoped that building developments may provide an equivalent structure in other materials.

221. Where such floors cannot be provided, and having in mind the possible widespread use of concrete or other solid flooring, we recommend that architectural consideration should be given to the provision in all working floors of horizontal grid pattern channels or ways of not more than 36-in. mesh and preferably 18-in. mesh. These might possibly be of $2\frac{1}{4}$ in. by $2\frac{1}{4}$ in. section, and would communicate with similar vertical channels in walls or partitions.

222. Under-floor steel or non-metallic duct systems, as described in *B.S.* 774 and *B.S.* 815, have advantages for certain types of buildings.

223. Failing the provision of hollow floors, floor-channels, or ducts, we recommend that the installation be carried out in conduit as proposed in paragraph 219. The runs should be placed at convenient uniform intervals across the floors, spaced according to the purpose of the building and to probable future electrical developments. Two conduit systems will generally be required, the first to serve the socket-outlet requirements of the particular floor, the second the ceiling lighting, fans, etc. on the storey beneath. Reserve conduits or conduit space, with convenient draw boxes, should be provided for future developments.

INSTALLATION DIAGRAM

224. A clear and accurate diagram, showing the location of cable ways and cables throughout the building, should be kept available for easy reference at any future time, and should preferably be displayed in the switch room of the building. A routine should be established whereby this diagram is kept constantly up to date.

IDENTIFICATION

225. All conduits, ducts, and cables should be identified in accordance with the current recommendations of the relevant British Standard.

LIGHTING

226. *General Lighting.* Some aspects of this problem are dealt with in subsequent sections, but it is assumed that detailed recommendations will be given in the Report of the Lighting Committee in this series.

227. *Stair, Corridor, and Entrance Lighting.* Adequate corridor and entrance lighting must be provided. Stair lighting should be controlled by main switches at the foot of each staircase, arranged to control one or more lights. These switches should be recessed in a cupboard, located in a commissionaire's or caretaker's office, or otherwise made inaccessible to unauthorized persons. In certain cases, time switch control or time delay switch control may be desirable. Corridor lighting should generally be controlled from convenient points adjacent to the staircases.

228. *Emergency Lighting.* In certain classes of buildings statutory regulations may require secondary lighting. This may be conveniently provided by a separate installation supplied from a trickle charged battery. An automatic switch should be provided to cut in the emergency lighting in the event of failure of the main supply.

SPACE HEATING

229. Direct electric space heating may be effected by radiant electric fires, convectors, tubular heaters, wall or ceiling panels, or other appropriate means.

TEMPERATURE CONTROL EQUIPMENT

230. Many post-war buildings will be provided with temperature control or air-conditioning installations. Several modern systems require that climate-sensitive control apparatus be located outside the building. The location of such apparatus will require to be carefully chosen in consultation with the temperature control engineer, and due provision made for its installation without disfigurement to the exterior of the building.

231. Thermostatic installations for the control of temperature in individual rooms require similar forethought.

POSITION AND MOUNTING OF SWITCHES, SOCKET-OUTLETS, SIZE OF FLEXIBLES, ETC.

232. The recommendations contained in paragraphs 73, 74, 92, 93 and 101 are generally applicable.

COMPOSITION FLOORS

233. Where corrosive floor compositions are to be used, metal conduits should be given suitable protective treatment; alternatively non-metallic conduits should be employed.

RELATION TO OTHER SERVICES

234. Contact between incoming service cables, installation conduits, and cables and gas, water, or other metal service pipes or conducting material should be avoided by spacing, insulation, or other means.

235. The transformer substation or control room should be reserved for electrical equipment only, but there is no objection to this room being adjacent to the control room or rooms of other services.

CLOCKS, BELL SYSTEMS, STAFF LOCATING SYSTEMS, SERVICE CALL SYSTEMS, FIRE AND BURGLAR ALARMS

236. Detailed recommendations are given in Part III, Section 6.

PROTECTION AGAINST LIGHTNING

237. Lightning conductors should be provided in accordance with Code of Practice C.P.1. 1943, "Recommendations for the protection of structures against lightning."

SECTION 2. SPECIAL REQUIREMENTS OF INSTALLATIONS IN BLOCKS OF FLATS

INTERNAL ARRANGEMENTS IN INDIVIDUAL FLATS

238. Detailed recommendations are given in Part I.

DISTRIBUTION AT EACH STOREY

239. We recommend that on each storey each vertical duct or chase should be associated with a sealed distribution board provided with single-pole fuses to correspond with the number of tenants to be served. Standard enclosed cartridge type fuses should be used, and these and their carriers should be so designed as to ensure that only fuses not exceeding the maximum ratings of fuse carriers can be inserted. From the distribution board, conduit should be run along corridors

in a floor duct or in a hollow ceiling to the consumers' supply controls in the individual premises.

240. Where each tenant is to be provided with a prepayment meter this should be incorporated in a consumer's supply control unit containing, in addition, a main switch and fuses generally as recommended for domestic premises in paragraphs 34 36. Appropriate architectural provision should be made for convenient and unobtrusive flush-mounting of the unit in each consumer's premises.

241. Where quarterly meters are to be used, consumers' supply control units incorporating this type of meter may be installed in each consumer's premises, or alternatively, the meters may be assembled at the position of the sealed distribution board on each storey, providing greater convenience in meter reading.

STAIR, CORRIDOR, AND ENTRANCE LIGHTING

242. The recommendations of paragraph 227 apply.

SECTION 3. SPECIAL REQUIREMENTS OF INSTALLATIONS IN OFFICES AND ADMINISTRATIVE BUILDINGS

SINGLE AND "MULTI-CONSUMER" PREMISES

243. Buildings for commercial, government, or other administrative purposes present similar problems. The only significant variation is that many offices are "multi-consumer" premises housing different concerns occupying individual rooms, suites, or floors, each requiring a separately metered supply, whereas in other cases a whole building may be occupied and controlled by a single business concern or by a single administrative authority. For these, separately metered supplies to rooms, suites, and floors are unnecessary, and the installation may be correspondingly simplified.

OCCUPIERS' ELECTRIC EQUIPMENT

244. In estimating the probable demand and in planning the installation, consideration should be given to the growing use of electrically operated office equipment, and to the use of small trade machinery, etc.

FLOOR INSTALLATION

245. See paragraphs 220 to 223.

SOCKET-OUTLETS

246. Standard socket-outlets and plugs, as already discussed (see Part I, paragraphs 92 and 93) should be supplied from the floor installation, and should be located on walls and stanchions at, say, 9 in. above floor level. In addition, water-tight floor socket-outlets connected to the conduit system should be provided, if required.

CONTROLS

247. The recommendations of paragraphs 239 to 241 will generally apply, but for one-tenant buildings local metering will be unnecessary except in special cases, and metering will generally be accomplished at the intake. The distribution fuse boards serving the rooms on each floor will be under the supervision of the maintenance staff of the building.

LIGHTING

248. It is assumed that detailed recommendations will be given in the Report of the Lighting Committee in this series.

249. The main space lighting should in general be designed as an installation fixed in relation to the stanchion bays, which need not be altered if movable partitions are rearranged. The present trend toward fluorescent lighting will probably become general in post-war years, and a fixed installation giving uniform illumination will be facilitated. Consequently a fixed system of ceiling conduits with the necessary outlets will generally provide a satisfactory installation. Where the main lighting needs to be supplemented by local lighting, the extra installation required will depend on the extent, purpose, and intensity of the local lighting.

250. In large areas the switching of lights in, say, three "zones," graded from the daylit zone to the darkest zone remote from the windows, is recommended, and for suitable cases photo-electric control can be usefully considered.

251. In certain cases it may be required to provide reduced lighting for cleaning purposes. Pilot lighting for night patrols may also be necessary.

STAIR, CORRIDOR, AND ENTRANCE LIGHTING

252. The recommendations of paragraph 227 apply.

EMERGENCY LIGHTING

253. See paragraph 228.

SECTION 4. SPECIAL REQUIREMENTS OF INSTALLATIONS IN DEPARTMENT STORES

ELECTRICITY SUPPLY INTAKE

254. The general provisions given in paragraph 211 apply, but an over-riding consideration that may affect the selection of transformer or switch-room accommodation is the value placed on space, including basement space, in department stores.

VERTICAL DUCTS OR CHASES

255. See paragraphs 213 to 217.

HORIZONTAL INSTALLATIONS

256. Convenient electricity supply is essential throughout the selling floors. As outlined in paragraph 220, a common practice has been to provide a wooden floor on bearers laid on the concrete. Inside the hollow floor space so obtained, ample accommodation is available for electrical conduits, sprinkler pipes, and cash delivery tubes: a very convenient arrangement. If post-war timber shortage limits the use of such floors, the alternative arrangements proposed in paragraph 221 may be considered.

257. As far as electrical requirements are concerned, we consider that a satisfactory installation can be obtained by placing steel conduit on the shuttering, in screeding of suitable depth, or in between floor blocks, as suggested in paragraph 219.

258. Whatever method is adopted, the layout of the conduit system from the vertical duct and distribution fuse board serving the floor should be planned at an early stage to have regard to the selling floor plan; the positions of show cases, cash desks, and so forth being taken into consideration.

SOCKET-OUTLETS

259. Liberal provision of socket-outlets is recommended. These are principally required for auxiliary lighting for display purposes, tank show cases, etc. Consequently the proposed standard socket-outlets and plugs will provide adequate capacity. In addition, it should be remembered that sales activities requiring power for special purposes may be established, possibly temporarily, in any part of the store. Hairdressing, photographic studios, exhibitions, radio, electric light fittings and appliance departments may be mentioned in this regard and should have special consideration and treatment. For general purposes, socket-outlets should be located mainly on the stanchions, and may be flush-mounted by sinking in the "hollows" of the usual H section girders, the concrete facings of which may be cut to accommodate fittings of overall depth of, say, $2\frac{1}{4}$ in. As many as ten socket-outlets may be required on a stanchion. In addition to these, each bay may be provided with 6 to 8 floor outlets connected to the conduit system by means of water-tight fittings. These will serve show cases or displays not convenient to the stanchion outlets; appropriate switching arrangements should be provided.

LIGHTING

260. It is assumed that detailed recommendations will be given in the Report of the Lighting Committee.

261. *Ceiling Lighting.* We consider that fluorescent lighting will be particularly applicable to department store lighting and that changes in past installation practice are therefore probable. Whatever the light source, a high intensity and even distribution of light on the selling floors is a constant requirement. The ceiling outlets may therefore be fixed in position, and the conduit system may also be permanently installed as proposed in paragraph 219.

262. *Switching of Ceiling Lights.* Switching of lights individually or in arbitrary groups, is not regarded as satisfactory. As proposed in paragraph 250, by arranging the lighting to be switched in three zones, daylit, medium, and dark, artificial lighting complementary to daylighting may be obtained. Thus at night or in dull weather each zone may be fully illuminated, but in clear daylight the "daylit" and "medium" zones may be extinguished. Each zone should be controlled by one switch or contactor, and photo-electric control can be usefully considered.

263. *Reduced Lighting and Pilot Lighting.* Pilot lights with appropriately placed switches should be provided for night patrols. Diminished lighting for the use of cleaning staff is not considered advisable.

264. *Stair, Corridor, and Entrance Lighting.* The recommendations of paragraph 227 apply.

265. *Emergency Lighting.* See paragraph 228.

266. *Advertising Display, Flood Lighting, etc.* Electrical provision may be required for advertising display and flood lighting. The architectural design of the building should be considered from this point of view, so that disfigurement to the building and to the appearance of the street may be avoided.

SECTION 5. SPECIAL REQUIREMENTS OF INSTALLATIONS IN HOTELS

267. Post-war hotels will have to provide comfort and convenience comparable with that to be provided in post-war homes. In addition, the facilities for foreign travel that will exist after the war will make it desirable that visitors to this country should enjoy standards of comfort and convenience comparable with the best to be found abroad. This is particularly important in view of our cold and damp climate, which makes it doubly necessary that foreign visitors should be welcomed in well-lit, warm, and comfortable hotels. With these considerations in mind we make the following recommendations.

BEDROOM LIGHTING

268. In all cases lighting should be provided for the dressing table (controlled by a switch at the door), at the wash-hand basin, and also at a bedside table or wall-bracket position (controlled by a bedside switch).

BEDROOM SOCKET-OUTLETS

269. At least two of the proposed standard socket-outlets should be installed in every bedroom for the use of visitors' "travelling" electric irons, razors, hair curlers, portable radio sets, and the like, and for the vacuum cleaning equipment of the staff. In bedrooms fitted with basins having hot and cold running water, particular care should be taken to ensure that the socket-outlets are placed far enough from plumbing fixtures to minimize the danger of a person touching these while using an electrical appliance. With this consideration in mind, we recommend that the socket-outlets be located beside the dressing table and beside the bedhead, in each case on the side remote from the basin. It is pertinent to note that electric shaving is a dry operation which can be performed at the dressing table.

BEDROOM ELECTRIC LOCKS

270. The provision of electric room locks controlled by bedside or table side switches may be considered. In pre-war years this facility was becoming increasingly common abroad.

BEDROOM SPACE HEATING

271. A radiant electric fire or electric convector should be provided for occasional or supplementary heating. A prepayment meter may be provided for this purpose, and may be incorporated in the design of the heating appliance or mounted in a suitably recessed cupboard.

SOCKET-OUTLETS IN PUBLIC ROOMS, STAFF ROOMS, AND CORRIDORS

272. Adequate numbers of socket-outlets should be provided in all public rooms, staff rooms, and corridors for the use of portable electric appliances, radio sets, vacuum cleaning equipment, etc. In no circumstances should socket-outlets be more than 30 feet apart. Their provision may be facilitated by the use of ring circuits.

GUESTS' LAUNDERING

273. Provision of a room equipped with a drying cupboard, electric irons, and other small laundering facilities should be considered.

SECTION 6. TELECOMMUNICATIONS IN MULTI-OCCUPIER AND SIMILAR BUILDINGS

A. COMMON TELECOMMUNICATIONS SERVICE INSTALLATIONS IN BLOCKS OF FLATS

274. Preceding sections of the Report deal with the telecommunication arrangements within individual flats. (Part I, Sections 1 and 2, paragraphs 106 to 129 and 161 to 170.) The present section is concerned with the common telecommunication services within blocks of flats. These may include direct telephone exchange lines, a private branch exchange with associated extensions, public call offices, and sound and vision broadcasting equipment for receiving, amplifying, and distributing the programmes received. Bell systems, fire alarms, etc. may also be required.

PRIVATE BRANCH EXCHANGES

275. In any block of flats the size of the private branch exchange will depend upon the number of telephones to be connected and the traffic handled. In many cases a small switchboard fitted in an office or caretaker's room may suffice, but in larger blocks a telephone switch room may be needed. Adequate floor space, convenient cable access, satisfactory amenities for the operators, and sufficient space for expansion to avoid the cost and disturbance of moving the exchange to another room at a later date are important factors. There are advantages in locating the exchange centrally in respect of the floors and rooms to be served. Freedom from noise is important, and if necessary sound insulation should be provided. Early consultation between the local telephone manager and others interested, as recommended in paragraph 72, is essential for a satisfactory plan to be achieved.

PUBLIC CALL OFFICES

276. One or more public call offices may be required and should be incorporated as built-in features of the architectural design of entrance halls or other selected locations.

SOUND BROADCAST PROGRAMMES

277. The direct reception of broadcast programmes by tenants may often be impracticable or unsatisfactory, as outside aerials for each flat are impracticable, and indoor aerials may be inefficient. For these reasons provision may have to be made for the internal distribution of broadcast programmes to individual flats throughout the building by one or more of the following systems:

i. Distribution to individual flats of high frequency signals as received on a common aerial and amplified as necessary, giving a wide choice of programmes.

In this case the type and location of the aerial will depend on local reception conditions. The initial H.F. amplification (prior to distribution) should be carried out near the aerial and, in large blocks, additional amplifiers at other points may have to be provided. A cable of special design will be required to distribute the amplified signals to the individual flats, in each of which an ordinary radio receiving set may be used for reception.

ii. Reception on a single aerial, with receiving and amplifying apparatus to distribute a limited choice of programmes to the individual flats.

As in (i) an aerial will be required to feed the receiver(s) which should be accommodated conveniently near. The power amplifier may be with the receiver or at some central position in the building. One independent circuit will be required from the amplifier to the flats for each programme distributed. The receiving equipment in the flats will consist of loud-speakers and selector switches.

iii. Distribution to individual flats of a limited choice of programmes received by wire from a relay exchange or elsewhere.

The service should be brought in at a convenient point, from where, in small blocks, it may be distributed to individual flats. In larger blocks, an amplifier will be required near the leading-in point or at some convenient central point, from which an independent circuit to the flats will be required for each programme as in (ii), and the receiving equipment will consist of loud-speakers and associated programme selector switches. This system requires no local aerial.

Other systems, or variations of these systems, may be developed after the war.

TELEVISION

278. Television will probably develop rapidly after the war, but the most suitable methods of distribution cannot yet be specified in detail. We recommend, however, that space at least equal to that required for sound broadcasting, and at the same points, be provided and reserved for the accommodation of television equipment and cabling.

BELLS

279. In addition to door bells a system for calling attendants may be required. Numerous systems have been developed using bells and either mechanical indicators or lamp signals. The system most suitable for a particular case will depend upon the services to be provided. Precautions should be taken to suppress radio interference.

CLOCKS

280. Clock positions should be determined at an early stage, so that suitable flush-mounting recesses may be provided and provision made for the necessary wiring runs. Mains driven clocks may be used where the frequency of the electric supply is controlled; alternatively, an impulse clock system may be installed. In the latter case a master clock, secondary battery, and charger will be necessary, and may be conveniently accommodated in the control room proposed in paragraph 286. Precautions should be taken to suppress radio interference.

FIRE ALARMS

281. Fire alarm systems may be required. Numerous systems controlled by press button and/or thermostats are available, and may be operated from the electric supply mains or by means of batteries. In all cases bells or other audible warning devices will be required where they can be heard throughout the building, and in addition it may be desirable to give at various points an indication of the site of the alarm or fire. Direct connection to the nearest fire station may be desirable.

Provision for Wiring

LEADING-IN

282. Facilities will be required for leading-in telecommunications services from underground or overhead distribution systems. It is not expected that an overhead system will be used except in smaller buildings in rural areas, and as a general rule the lead-in will be from underground.

283. For leading-in Post Office services from underground, a pipe or conduit of suitable size will be required to be fitted or built in through the outer wall of the building for linking up the Post Office external duct system with the internal duct system. The location and provision to be made for leading-in should, in all cases, be agreed with the telephone manager.

284. Leading-in from overhead to individual premises should be effected in a manner similar to that described in paragraphs 26, 111, and 118.

285. The method of leading-in from a common aerial will be determined by the relative location of the receiving equipment. If this is adjacent a simple lead-in tube through the outer wall or roof may be used. Alternatively, if the receiving equipment is remote from the aerial, a screened down lead or anti-interference aerial system (if only one receiver is required) or a community aerial system (if more than one receiver is required) will be necessary. A competent electrical contractor should be consulted regarding the provision to be made in any given case.

CONTROLS

286. Controls are required at or near the point of entry of the main cables for telephone and wire broadcasting services, not only for terminating and external cables but also for testing and cross connection to internal cables. The space allocated should be adequate to house the necessary equipment and to permit extensions of the various services. In the larger buildings this space should take the form of a control room, which when convenient will be shared by the various telecommunication services. The position chosen should be related to the main cable runs. In suitable circumstances one room may serve both as control room and telephone switch room.

287. Sub-controls may be required on the various floors. These may be accommodated in the vertical duct if space permits, otherwise recesses or other accommodation should be provided.

VERTICAL DUCTS OR CHASES

288. In any block, one or more vertical ducts or chases should be provided. The number will depend upon the size and configuration of the building. In order to keep the bulk and length of horizontal wiring to reasonable proportions, the vertical ducts or chases should generally be not more than 100 ft. apart as measured along the corridors. Separate ducts or chases for the telecommunication services are preferable, but those for other services may be shared, provided that adequate segregation, *e.g.* by means of suitable fillets, is arranged. On this basis spaces not less than 4 in. wide by 2 in. deep will be sufficient to accommodate all the telecommunication services, though subdivision of the space by fillets may be required to segregate the services in accordance with their working voltages.

HORIZONTAL RUNS

289. Horizontal runs will be required between the lead-in point, the main control, and the vertical ducts. If a basement is included in the building the

main horizontal run will probably be most conveniently located therein. On each floor, horizontal runs will be required between the vertical ducts or chases and the various flats or rooms, to link up with the provision for wiring recommended in paragraphs 129, 161, 162, and 168, and also for the wiring of the apparatus or appliances fitted in the public parts of the building. These runs may be provided by means of under-floor ducts or conduits, floor ducts or chases, hollow detachable skirtings, wall grooves with detachable covers, or hollow ceilings. Attention is drawn to the advantages of multiple-way under-floor ducts of the types described in *B.S.* 774 and *B.S.* 815 for the use of electricity supply, communications, and other services. Whichever method be adopted, it is essential that adequate accommodation and access be provided for additional services and extensions.

290. Metallic ducts or conduits must be of a type which will ensure ample and permanent electrical conductance and mechanical rigidity throughout, and must be effectively connected to earth. All bends and tees should be of the inspection type, and ample draw boxes should be provided. Where located under the floor, access should be provided by means of small sections of screwed floor boards or other suitable floor traps. Pipes or cables used for the telecommunication services should be run so that they shall be readily accessible at any time. To avoid disturbance to floor coverings, the under-floor ducts or conduits for telecommunication services can, with advantage, be located at the sides of corridors.

SEGREGATION OF WIRING

291. In the circumstances described in Regulations 315 (c) and 903 of the Wiring Regulations, separate conduits for the accommodation of the telecommunication services and the electric supply services are necessary. In addition, Post Office telecommunication wires must not be run in the same conduits as:

i. High signal-level circuits used for relaying broadcast programmes.

ii. Wires associated with fire alarms, burglar alarms, clocks, bells, or other devices operated from the electricity supply mains, unless the supply from the mains is derived in a manner approved by the Post Office.

RADIO INTERFERENCE

292. The recommendations of paragraphs 126, 127, and 170 apply.

POWER SUPPLY

293. Power supply with a control panel may be required in the telephone switch room and at other points where telecommunications equipment is installed. Adequate lighting should also be provided at these points, and heating and ventilation where necessary.

B. TELECOMMUNICATIONS SERVICE INSTALLATIONS IN OTHER LARGE BUILDINGS, INCLUDING OFFICES AND ADMINISTRATIVE BUILDINGS, DEPARTMENT STORES, AND HOTELS

i. *General Requirements*

294. The extent to which telecommunication services are required in a building depends upon its function. When a building is to be occupied by more than one organization, there may be divergent requirements, all of which must be met. In addition to telephone instruments, radio receivers, loud-speakers, bells, press

buttons, indicator lamps, etc. much associated equipment must also be accommodated. For the reception of broadcast programmes, a suitable aerial will be required. Adequate space for all this equipment must be allowed for when the building is designed. In many cases appliances and fittings may with advantage be flush-mounted, and larger units can be built into recesses provided for the purpose.

295. The scope of telecommunication service continues to grow. This fact, coupled with the possibility of frequent changes of occupancy and use, has a considerable bearing on the recommendations of this section of the Report. It cannot be too strongly emphasized that adequate provision must be made for flexibility and expansion both in regard to accommodation for controls and other apparatus and for cabling and wiring.

TELEPHONE SERVICES CONNECTED TO THE PUBLIC SYSTEM

296. These may include one or more of the following:

i. A simple exchange line with one telephone or a combination of one or two exchange lines with extension telephones.

ii. A private manual branch exchange (P.B.X.) or private automatic branch exchange (P.A.B.X.) serving a number of direct exchange lines, with extension telephones as required.

iii. A house exchange system with up to two exchange lines and ten extensions. (A house exchange system does not require a branch exchange operator.)

iv. Public call offices. These may be required in all large buildings of the types under discussion, and consideration should be given to their incorporation as built-in features of the architectural design of the entrance hall or other selected positions.

TELEPHONE SERVICES NOT CONNECTED TO THE PUBLIC SYSTEM

297. Intercommunication service may be given by private automatic exchanges, private manual exchanges, house telephone systems or private wires.

ACCOMMODATION FOR SWITCHBOARDS FOR PUBLIC AND INTERNAL SYSTEMS

298. *Standard Switchboards.* In most buildings accommodation will be required for a standard type of switchboard. In certain circumstances this may be housed in a common or general office, but where more than one operator's position is required a separate room is preferable.

299. The room provided for a large P.B.X. must have adequate floor strength, convenient cable access, satisfactory amenities for the operators, and sufficient space for expansion without the cost and inconvenience of transferring the exchange elsewhere at a later date. A central location adjacent to the cable risers is desirable. This should be chosen as early as possible to ensure adequate cable runs and convenient cable distribution.

300. In addition to the room for the switchboard(s), a P.A.B.X. or large P.B.X. may need a separate apparatus room and a separate battery room, preferably adjacent.

301. *Special Switchboards.* Department stores, news distributing agencies, stockbroking offices, etc. may require additional special switchboards, which will form the subject of special consultations between the interested parties.

TELEGRAPH SERVICES

302. Direct telegraph circuits connecting the premises of large organizations are sometimes required. Teleprinters are usually installed, but other telegraph instruments may be used in certain circumstances.

303. A teleprinter may also be associated with any telephone instrument connected to the public system. This arrangement, known as the Telex system, permits communication by telegraph between any two such installations via the public system.

304. A teleprinter requires a table approximately 36 in. by 30 in. for its accommodation. It gives rise to a certain amount of operational noise, and this should be borne in mind when selecting its location. In large organizations where several teleprinters are used a room should be set apart for their accommodation.

SOUND AND TELEVISION BROADCASTING

305. The extent to which sound and television will be required in business premises after the war is difficult to forecast, but it is expected that one or both will be required in social rooms, canteens, etc. and due provision should accordingly be made.

306. In department stores and in radio and electrical stores both sound and television services will probably be required. Satisfactory and flexible arrangements for demonstration purposes should be provided.

307. In factories a combined public address and sound broadcasting system will usually be required.

WIRE BROADCASTING

308. Wire broadcasting may be more common in urban areas after the war, and may be installed as an alternative to the direct reception of broadcasting.

PUBLIC ADDRESS SYSTEMS

309. A public address system consists of a number of loud-speakers installed at various points and fed from an amplifier, whose input may be from a microphone, a gramophone pick-up, or from a wireless receiver.

310. The system may be used for many purposes including announcements to the staff, "music while you work," announcements to customers in large stores, paging of visitors in hotels, or for locating staff, as an alternative to the methods described in paragraph 312.

ii. *Other Telecommunication Services in Large Buildings*

311. Other facilities that may be required include staff locating systems, bell systems, service call systems, fire alarms, burglar alarms, clocks, and watchmen's tell-tale clocks.

STAFF LOCATING SYSTEMS

312. In the buildings considered it may frequently be necessary to call members of the staff when they are away from their offices or usual locations. There are many systems available for this purpose, usually controlled from a central position. They may make use of mechanical indicators, coloured lamps, or illuminated numbers or names, associated with an audible alarm. These devices should be controlled by a switch in a convenient position and usually operated by the telephone operator or inquiry clerk. An aural method employing loud-speakers throughout the building, with a microphone at the central position and associated amplifiers, may also be used for this purpose. (See paragraph 310.)

BELL SYSTEMS

313. Bell systems may be installed in all classes of buildings, and will usually be fed from the electricity supply mains by means of a transformer. Alternatively, a battery supply may be used.

SERVICE CALL SYSTEMS

314. As an alternative to a system of bells for calling maids, waiters, or others, many luminous calling devices are available and may be preferred in hotels, hospitals, etc. Press buttons are installed at the various points or rooms from which calls may be made, and each actuates a signal indicating the room or point of call, and an audible alarm with a lamp signal or mechanical indication in the service room. In very large buildings having a number of floors, additional indicating devices (usually lamps) may be required to indicate the floor or section originating a call.

CLOCKS

315. The recommendations of paragraph 280 apply.

316. Watchmen's tell-tale clocks, of which several types are available, may be required in certain classes of buildings. The master recorder can conveniently be installed in the main control or telephone room, with key-switches or contact boxes at various points throughout the building.

FIRE ALARMS

317. The recommendations of paragraph 281 apply.

BURGLAR ALARMS

318. Burglar alarms may be required. Several types of equipment are available, and concealed accommodation for certain apparatus, wiring, and batteries will be required.

iii. *Control of Services*

319. The recommendations of paragraphs 282 to 293 will generally apply, and where a building is occupied by more than one organization an individual control may be required for each. In these circumstances a main control room to house the apparatus common to the whole building would be required in addition.

320. As a guide to the amount of accommodation required for a combined switch room and main control room, we give the space requirement of a typical installation in a building wholly occupied by one organization and embodying the following services:

2 switchboards (for 2 operators)
1 teleprinter in same room
1 staff locating system
1 impulse clock system
1 fire alarm system.

For this installation a joint switch room and main control room of approximately 150 sq. ft. is required.

iv. *Provision for Wiring*

321. The buildings dealt with in this section vary considerably in design and construction, and their telecommunications requirements will be so varied that no definite details of the actual accommodation required for cabling can be given. The following recommendations may be regarded as a general guide.

322. The layout of wiring must receive consideration during the preparation of the building plans. Experience shows that extensions and modifications are constantly required, and therefore a scheme allowing for maximum flexibility and adaptation is the only suitable method for meeting future demands and developments.

RELATION TO OTHER SERVICES

323. It may be desirable to lead the telecommunications cables into a building at the same position as electricity cables and gas and water pipes. In these circumstances, spacing of at least 2 in. between the telecommunication cables and any of the other services should be allowed, and a fillet should be provided to ensure that this separation is maintained. If high voltage cables enter the building and run adjacent to telecommunications cables a separation of at least 12 in. should be provided wherever possible. In difficult situations a reduced separation is permissible, provided that, where a separation of more than 6 in. is impracticable, concrete at least 2 in. thick is provided between the two sets of cables. The recommendations of paragraph 291 should be observed.

FLEXIBILITY OF CONNECTION

324. In large office buildings, department stores, or other premises where there are rooms or offices in which a number of telephones, teleprinters, etc. will be used, horizontal runs will be required from sub-controls inside the rooms to the positions where instruments are to be fitted. It is often desirable to move office desks, store counters, etc. with the consequent removal of the telephones, teleprinters, or other equipment. Any scheme of horizontal runs should, therefore, be arranged to give maximum flexibility, and the recommendations of paragraphs 289 and 290 should be observed.

POWER SUPPLY

325. The recommendations of paragraph 293 should be observed.

RADIO INTERFERENCE

326. In addition to the preventative measures mentioned in paragraphs 126 and 127, special attention should be given to the adequate screening of any rooms, laboratories, and workshops in which high frequency apparatus such as electro-medical diathermy equipment, spark spectrographs, high frequency electric furnaces, eddy current heaters, and the like may be used. The procedure to be adopted in these cases is given in paragraph 170.

PART IV. ELECTRICITY IN SCHOOLS

SECTION 1. ELECTRICAL INSTALLATIONS

GENERAL

327. In the post-war building programme we understand that the provision of new schools will rank in priority second only to housing.

328. In urban areas in the past, schools of two or more storeys have generally been built. The arrangement of the electrical installation of a school building of this type is similar in essentials to that required for other premises of similar size; hence the recommendations contained in Part III, Section 1 (paragraph 211 *et seq.*) are generally applicable. In suburban and rural areas single storey construction was becoming increasingly common in pre-war years, and it would appear that this trend is likely to be accentuated in the post-war period and that the majority of schools, both in urban and rural areas, may be of this type.

329. A set of plans referred to us by the School Buildings Committee shows a single storey "modern" school for 360 children composed of standardized unit

buildings designed for rapid erection.[1] The units comprise classrooms, practical rooms, assembly hall, gymnasium, cloakrooms, kitchen, etc. These may be grouped in several ways to suit various site conditions. The units are designed for assembly with space between each, so as to ensure adequate daylighting and silence. The units are jointed by flat-roofed corridors. The structure consists of a light steel framework assembled from standard units each 99 in. long. The floor to ceiling height of the flat-roofed corridors is 8 ft., and of all teaching rooms, 11 ft. The rooms of the building are roof spanned with steel trusses of so low an angle as not to provide a creep space, access to the roof space being obtained by ceiling panels which are removable.

330. We have examined this provisional design, and in the following paragraphs proposals are made regarding the best method of providing a flexible electrical installation in such a building. We emphasize that at this early stage, in the absence of final data on the detailed design and provisions to be made in the school, consideration has been restricted mainly to those matters which affect the construction of the building in order to ensure that suitable provision may be made in the building design for the electrical installation.

331. Although the following recommendations are related to the specific type of school described above, they apply in their main particulars to schools in general.

ELECTRICITY SUPPLY INTAKE

332. The capacity of the service cable required will be determined by the supply engineer, having regard to the size and type of school, and upon the extent to which electricity is to be used. For a school of the type under review the cable should have a capacity of not less than 50 kw. This would cover lighting and general utility socket-outlets for auxiliary space heating and water heating, laboratory, and domestic science requirements, staff rooms, and general educational supplies. Greater cable capacity will be required for domestic science and technical schools, schools in which provision is to be made for general space heating, or for electric kitchens for school meals.

333. It is essential to provide a suitable space for the intake apparatus and switchgear, so far as possible towards the centre of load of the building. The design of the building provides for store rooms measuring 8 ft. by 8 ft. by 8 ft. high, entered from the corridors between classrooms. One of these, centrally located, is regarded as suitable for the intake apparatus and switchgear. It is assumed that, if a transformer is required, an outside brick or concrete house will be provided.

WIRING SYSTEM

334. We consider that insulated cable run in screwed or lug-grip-jointed welded or brazed steel conduit, as already recommended (see paragraph 219), provides a system which is generally speaking preferable to any of the alternative methods or systems. It is recognized, however, that certain alternative methods have advantages where facility of alteration is required.

LAYOUT OF WIRING

335. In the proposed single storey construction, the only practicable route for the main runs of wiring is within the ceilings of the flat-roofed corridors. It is recommended that a space 3 in. deep and at least 3 ft. wide be provided within this ceiling with access by means of removable ceiling panels. From this corridor ceiling space the conduits will pass through the hollow walls to the roof space above

[1] Since published in Post-war Building Studies No. 2: *Standard Construction for Schools.*

the classrooms and hall for distribution as required, and will pass down within the walls to switch points and socket-outlets. The permanent wiring in classrooms, staff rooms, etc. should be sunk, and flush-mounted accessories should be used. Socket-outlets should be provided, one adjacent to the teacher's desk and one at the opposite end of the room. In the practical rooms the need for flexibility may be met by using surface wiring or by using ducts as referred to in the next paragraph. Where apparatus is required in the middle of the floor, as for benches in practical rooms, we recommend that suitable channels be provided in the floor itself.

PREFABRICATION

336. As consideration is being given to prefabricated wall panels, we particularly urge that there should be at least one vertical duct or channel in each. The internal dimensions of the channel should preferably be of the order of 3 in. by $1\frac{1}{4}$ in. This provision obviously requires detailed consideration but the advantages to be obtained are very great. Such a system could obviate surface wiring in the practical rooms and would enhance the flexibility and convenience of the whole installation.

LIGHTING

337. It is assumed that detailed recommendations will be given in the Report of the Lighting Committee. The installation suggested above is adequate for any system of lighting that may be desired.

SPACE HEATING

338. When main space heating by electricity is desired, this may be effected by means of radiant electric fires, convectors, tubular heaters, by wall or ceiling panels or by heating elements or cable incorporated in the floor, or by appropriate combinations of these means. Apart from main space heating, auxiliary heating by means of radiant electric fires or convectors is likely to be required in any case in staff rooms and in the medical inspection room.

EDUCATIONAL EQUIPMENT

339. In domestic science rooms electric cookers, irons, and laundering equipment will be required and provision should be made for their connection and supply. In senior handcraft workshops the installation should be designed to supply drilling machines, lathes, soldering irons, and the like. In laboratories, socket-outlets at each working position may be required.

DRYING ROOMS

340. The plans show special drying rooms for children's clothes. Electricity is particularly suitable for this purpose, as clothes may often have to be dried at times of the year when the space heating system is not in operation. We recommend that each of these rooms be equipped with suitable heaters or fan heaters.

HAND-WASHING AND DRYING

341. Supplies of hot water for hand-washing will normally be provided from the main domestic hot-water system, but where scattered lavatory accommodation is required, local water heaters may often prove more convenient and economical.

342. It is generally recognized that school towels may constitute a vehicle of infection. Electric hand dryers which, on pressing a pedal, direct a draught of warm air over the hands, provide an alternative which should receive consideration in future.

SCHOOL MEALS

343. Having regard to a recent circular issued by the Board of Education,[1] it is clear that a large number of schools will, in future, be equipped for cooking a mid-day meal for substantially all their scholars. School kitchens for this purpose may be equipped with electric cookers, urns, mixers, and other facilities, for which the installation may accordingly be planned.

PROVISION FOR OUTBUILDINGS, PLAYGROUND LIGHTING, FLOOD LIGHTING, ETC.

344. Ducts under the asphalt playground to outbuildings, to a sports pavilion, or for playground lighting, may be required for electricity supply and telecommunications, and provision for future extensions will be advisable. Such ducts should be laid not less than 12 in. below the surface.

SAFETY CONSIDERATIONS

345. To ensure the safety of children, socket-outlets should in all cases be of the design recommended in paragraph 84 (i). To limit damage or tampering by the children, concealed or flush-mounted fittings should be used wherever possible. These should be allowed for in the design of the building, in which suitable recesses should be provided wherever required. We do not regard keyed switches as necessary or desirable.

SECTION 2. TELECOMMUNICATIONS

TELEPHONE SERVICE CONNECTED TO THE PUBLIC SYSTEM

346. The number of telephones required will depend upon the type of school. We expect that in the future, telephones will be required in most schools in positions such as the headmaster's room, caterer's office or kitchen, the caretaker's quarters, medical or dental clinics, general and other offices, and possibly the headmaster's house. These may be served by direct lines to the public exchange or through a private branch exchange. In schools for senior students or adults, one or more public call offices may be required and should be incorporated as built-in features of the design of the entrance halls or other selected locations.

SOUND AND TELEVISION BROADCASTING

347. The use of radio in schools will certainly develop, and consideration should be given to the provision of adequate facilities for the reception of one or more sound and vision programmes with facilities for distribution as required to any classroom. In each classroom provision should be made for a bracket or suitable stand for the loud-speaker, or preferably this may be permanently installed. The receivers should be housed in a control room which should be free from vibration and unauthorized interference. A suitable aerial should be provided adjacent to the control room and should be installed during building operations. An effective earth should also be provided as described in paragraph 121.

348. As quality of speech reproduction is an important factor in the reception of broadcasts in schools, attention should be paid to the acoustic properties of classrooms or halls where broadcast lessons will be taken. Steps should be taken to prevent bass reverberation, particularly if special rooms are being set aside for receiving programmes. It should be realized that although the acoustic properties of a room may be satisfactory for normal speech, they may not be so for broadcast reception.

[1] *School Meals : An Accelerated Programme,* Board of Education Circular 1629, 15th May 1943.

PUBLIC ADDRESS SYSTEM

349. A public address system to enable the headmaster or others to address the students in the various classrooms or halls may be required. Such a system requires provision for a microphone, probably on the platform of the hall or in the headmaster's room, an amplifier in the control room, and loud-speakers in the classrooms and halls. This system can well be combined with that for the distribution of the radio programmes.

BELLS

350. Class changing bells controlled by suitably located press buttons will be required in positions where they can be heard in all classrooms. The system can be operated from the electricity supply by the use of a suitable transformer. Door and miscellaneous bells may also be required and can be similarly operated. The requirements of paragraph 291 should be observed.

CLOCKS

351. The recommendations of paragraph 280 apply.

FIRE ALARMS

352. The recommendations of paragraph 281 apply.

PROVISION FOR WIRING

353. The methods of leading-in the services are described in paragraphs 109 to 114. Conduits or ducts for the accommodation of the wiring for the telecommunications services should be provided during the construction of the building. The sizes of conduits will depend upon the services required and the size and layout of the building. The type of conduit and method of installation may be similar to that for the electricity supply. In the proposed "modern" school the 3 ft. space in hollow corridor ceilings proposed in paragraph 256 would also provide adequately for telecommunications.

354. Circuits should be segregated in accordance with paragraph 291.

355. Outlets will be necessary at all points where instruments and accessories are to be fitted, and at the leading-in points from overhead and underground services. Means for connecting an earth wire to the main water supply or to an earth plate will also be required.

TELECOMMUNICATIONS CONTROL

356. In the plans for a "modern" school for 360 children, one of the store rooms measuring 8 ft. by 8 ft. by 8 ft. high (paragraph 333) would be suitable for housing the terminating, testing, and control apparatus. The setting apart of a room for the special purpose of telecommunication services control is not essential if the apparatus can be installed in an office or telephone switch room, where it will be free from unauthorized interference, and suitably located for cabling and maintenance and for personal control of radio programmes and record playing.

RADIO INTERFERENCE

357. The recommendations of paragraphs 126, 127, and 170 apply.

POWER SUPPLY

358. The recommendations of paragraph 293 apply.

PART V. ELECTRICITY IN HOSPITALS

SECTION 1. ELECTRICAL INSTALLATIONS

GENERAL

359. A hospital is a self-contained community whose successful functioning depends upon co-operation and orderliness. Full advantage of the advances in medical, electro-medical, and surgical practice, of dietetic knowledge, and of psychological treatment, can be obtained only if co-operation and orderliness are inherent in the design and installation of the building. For this reason the collaboration on which emphasis is laid in the Introduction is of unique importance in the planning of a hospital.

360. Quite apart from strictly medical and other functional considerations, it is not possible to over-emphasize the importance of a pleasant environment which will encourage the recovery of patients, and of good living quarters for the nurses and doctors. Again, in the light of modern dietetic knowledge, particular attention should be given to the kitchen, to its equipment, and to the serving facilities to be provided. Many existing hospitals are seriously deficient in these respects. The elimination of such shortcomings in future buildings is essential, particularly in view of the growing interest in the positive aspects of public health.

361. In all these matters, the electrical installation of a modern hospital plays an increasingly important part, and should be the subject of full discussion between the architect, the consulting electrical engineer and electrical contractor, and the surgical and medical advisers from the time when the plans are in their first stage.

362. In addition to the general service requirements referred to in paragraph 212, consideration will require to be given to laundering and to kitchen equipment including cooking, refrigerating, and trolley heating facilities. Satisfactory signalling systems for each patient and for calling the staff will be required. On the medical side the installation will be required to provide for X-ray plant, operating theatre equipment, sterilizers, ultra-violet and infra-red treatment, and for diathermy and other electro-therapeutic treatments. A cardiagraph and a motor-driven "iron lung" are other requirements. Electrical equipment is also commonly required in the pathological or research laboratory and in the dispensary. Teaching hospitals, lecture rooms, laboratories, and dissecting rooms, all require electrical facilities for which provision should be made at the outset.

ELECTRICITY SUPPLY FOR HOSPITAL INSTALLATIONS

363. Careful consideration has been given to the fundamental question as to whether electricity should be taken from a main supply or generated on the site in conjunction with the heating system. The conclusion has been reached that provided reasonable tariffs can be obtained there is rarely any financial advantage in generating locally, neither is there any fuel saving. It has been assumed, therefore, that energy will be taken from the mains, and that tariffs will be available which will make one system of wiring available for all purposes. Only in hospitals remote from supply mains will it be necessary to consider the question of generation. In these cases substantial plant will be necessary if X-ray equipment is to be satisfactorily operated. Such cases will necessarily require individual consideration in respect of their generating plant. Their installation requirements, however, will not differ substantially from those of a hospital supplied from the public mains.

ELECTRICITY SUPPLY INTAKE

364. In order to simplify the metering and to obtain the benefits of a maximum demand tariff, one intake is desirable, but there may be other considerations affecting a particular site which may necessitate more than one. In any case it is desirable that any private residential buildings associated with the hospital should be connected as individual consumers. An outside building or a basement is a convenient place for the main intake, which should be situated near to the centre of the load and conveniently for the incoming cables. The recommendations of paragraph 211 should be observed. In addition, the location of the transformer chamber, its acoustic insulation and the design of the transformer itself should be such as to prevent any disturbance by noise.

365. For the switchboard an uninterrupted wall space is essential, and although ventilation is necessary, window space should not unduly reduce the wall space. A room of low height is unsuitable; 8 ft. 6 in. should be regarded as the minimum. In large switch rooms it is frequently convenient to have along the switchboard a narrow trench, covered with floor plates, for cables. In cottage hospitals requiring only a small switchboard, an enclosure or lock-up cupboard should be provided.

INTERCONNECTION BETWEEN BUILDINGS

366. Where it is necessary to interconnect various buildings, the use of paper-insulated lead-sheathed cable is recommended, either armoured, laid direct in the ground, or unarmoured drawn into stoneware ducts. When sub-mains are to be laid between buildings for other services, there is no objection to these being laid in the ducts with the cables, provided contact between them is prevented by means of spacing or insulation. (See paragraph 234.) Paper-insulated lead-sheathed cable should be used, and this need not be armoured unless the cable is laid on the floor of the duct.

367. Consideration may be given to the possible advantages of ring mains.

VERTICAL DUCTS OR CHASES FOR RISING CONDUCTORS

368. The recommendations contained in paragraphs 213 to 217 should be observed. The question as to whether separate rising ducts or chases should be provided to the wards, operating theatres, etc. may be determined by the design of the building. General wards may be conveniently supplied by means of a vertical duct or chase rising behind the walls of the ward kitchens, in each of which a local fuse board may be recessed into the duct.

HORIZONTAL INSTALLATION

369. In large hospitals recommendations contained in paragraphs 218, 219, and 224 are generally applicable. In small hospitals with wood joist floors, conduits may be run in the normal manner, or on top floors they may be run in the loft space. Conduits should be run to follow the wall lines so far as may be practicable, and a draw-in loop-in system of wiring should be adopted. Horizontal distribution to the bedside panel positions, to which reference is made in the next paragraph, may be effected by running conduits in a chase or duct cut or prefabricated in the wall at 4 ft. 6 in. above floor level. The conditions regarding segregation of telecommunications and other wiring, stated in paragraph 291, should be observed.

BEDSIDE PANELS AND SOCKET-OUTLETS

370. A small wall panel should be provided at, say, 4 ft. 6 in. above floor level at each bed position. This should carry a bracket light with dimming switch, a bell push of the pendant type (which may be arranged to be removable), a

2-pin socket-outlet for wireless headphones, and a 3-pin standard socket-outlet for other purposes. These panels may be recessed in the walls, if the bed positions are predetermined. For the convenient use of portable X-ray apparatus and other appliances 3-pin 15-ampere shuttered socket-outlets should be provided at approximately 9 in. above floor level conveniently for, say, every 4 to 6 beds. These may be arranged on a ring circuit since the amount of apparatus likely to be in use at one time is limited.

LIGHTING

371. *General Ward Lighting.* The possibility of using fluorescent lamps has received preliminary consideration, but it is assumed that this matter will be covered by the Report of the Lighting Committee in this series.

372. Provision should be made for low intensity lighting of wards by night.

373. *Operating Theatre Lighting.* A "shadowless" lamp will be required over the operating table, and provision should be made for fixings to support its weight. For general theatre lighting, consideration should be given to fluorescent lamps. These might be of the recessed type to give a "clean" design and appearance to the theatre.

374. *Emergency Lighting.* This should be provided in the operating theatres. Certain circuits may be required elsewhere. (See paragraph 228.)

SPACE HEATING

375. The facilities for general space heating by means of electricity are summarized in paragraph 229. In certain places, for example in sunray treatment rooms, and notably in the operating theatre, a high air temperature is necessary, and for this purpose thermostatically controlled electric heating may conveniently be used. Open element electric heating appliances are not admissible in operating theatres.

376. A special case in which electricity may be of considerable assistance arises where space and water heating are required at isolated points, as for example in a hospital whose buildings are detached or dispersed. The necessary cables may be run in underground ducts as proposed in paragraph 366.

REFRIGERATION

377. In addition to the main refrigeration requirements, consideration should be given to the advantages of small refrigerators in the ward kitchens, the staff quarters, and elsewhere.

X-RAY APPARATUS

378. Fluctuations or drops in voltage make X-ray diagnosis extremely difficult. Supply cables of adequate capacity should be used, and the connection of other plant to them should be avoided. Automatic voltage regulating equipment may be necessary if the X-ray department is far from the intake.

SPECIAL FACILITIES IN OPERATING THEATRES

379. It is becoming increasingly common to provide a short vertical pillar of rectangular section behind the operating table to accommodate the gas and + and − air pressure tubes used by the anaesthetist. On the sloping desk top of this pillar a headlight and cautery transformer are recessed, and, on the sides, flush switches and socket-outlets for various electrical appliances and, sometimes, a switch for controlling the exhaust fan are provided. Conduit for the cables to this pillar must be provided under the floor.

SAFETY IN OPERATING THEATRES AND ANAESTHETIC ROOMS

380. The Operating Theatres Electrical Apparatus Committee of The Institution of Electrical Engineers have reviewed the question of safety measures, and they have prepared recommendations in the form of a Warning Notice for display in operating theatres. This has been adopted in a modified form and issued to those concerned by the Ministry of Health.

SECTION 2. TELECOMMUNICATIONS

TELEPHONES

381. Public and internal telephone systems will be required for administrative purposes generally as described in paragraphs 294 to 326. In addition, in private wards, facilities to plug in a telephone for connection with the public exchange system may need to be provided for the occasional use of convalescent patients.

BROADCASTING

382. Headphones should be provided for the reception by each patient of sound broadcasting programmes. An alternative programme may possibly be provided. Sound and television reception will probably be required in the doctors' and in the nurses' common rooms. The recommendations contained in Part III, Section 6 (paragraphs 274 to 326) are generally applicable.

CLOCKS

383. The recommendations of paragraph 280 should be observed.

STAFF LOCATING SYSTEMS AND PATIENTS' CALL SYSTEMS

384. The recommendations of paragraphs 312 to 314 should be observed. Visual rather than audible calling devices will generally be required.

PART VI. ELECTRICITY IN FARM BUILDINGS

POST-WAR FARM BUILDINGS

385. Post-war development appears likely to consist mainly of the modernization and reconstruction of existing farms by the erection of new specialized buildings, or the replacement or extension of existing buildings. It is probable, however, that a relatively small number of new farms will be required, either to replace obsolete farms or for reasons of change in the method or type of farming.

386. Our recommendations have been so prepared as to ensure adequate electrical installations both in these and in existing farm buildings. In England and Wales there is no legal obligation for a landlord to compensate a departing tenant for the improvement of farm property by installing electricity, whereas there is such an obligation in Scotland. This has a serious effect on the provision by English tenants of adequate and satisfactory installations. So long as this situation continues we consider that greater co-operation between landlord and tenant is an essential factor.

387. An essential first step in electrification is that full consultation should take place between the farmer, the architect and/or builder, the electricity supply engineer, the electrical contractor, and possibly the maker of any new type of equipment which may be under consideration. The decision whether the supply shall be given from underground or overhead will be taken by the supply engineer, who should also specify the requirements for external fixtures or the like that may

be necessary, and the provision to be made for earthing. At this stage consideration should also be given to the route of supply lines, and to the placing of poles with due regard to farming operations and to rural amenities.

388. The use of mechanized methods may influence the design of farm buildings. Thus, a two-storey layout is preferable where electrically driven mechanical feed handling and storage is to be adopted, so as to provide for gravity feed from the first floor to the ground floor. This also involves the provision of a structure adequate to support considerable storage weight Or again, in a dairy no separate boiler room is required when electrical sterilization is employed. In the consultations referred to above, consideration should be given to such factors, in so far as they may influence the design of new farm buildings or of modifications or extensions to existing farms.

FARM ELECTRIFICATION

389. In pre-war years electricity had already found a wide variety of applications on the farm. Electric lighting, pumping, milking, cooling, sterilizing, water heating, incubation and rearing, feed grinding, cutting, pulping, threshing, and sawing may be mentioned as typical established practices. A wide variety of other major and minor applications are either established or in course of development both in this country and abroad. Apart from any intrinsic merits of electrically operated processes, increased cost of farm labour will encourage mechanization and automatically controlled processes, and the necessity for making farm work more attractive by reducing heavy manual and repetitive work and minimizing attendance outside normal working hours will have a similar effect.

390. In addition, the necessity for providing domestic amenities in farmhouse and cottage equivalent to those available in towns is of increasing importance.

WATER SUPPLY

391. In localities in which there is no public water supply, but where there is a suitable local source of water, an automatic electric pumping system will give the same convenience. Where the source is constant, as is generally the case, the pressure tank system may be used in order to dispense with the need for storage tanks and the structural provision required for them, and to give the benefit of a high-pressure water supply. On the other hand, a storage tank system ensures a reasonable reserve of water at times when the pumping plant may be receiving maintenance attention.

TYPE OF ELECTRICITY SUPPLY

392. We assume that after the war electricity will be made generally available in rural areas, and that the great majority of farms will be connected to public supply mains. Although rural three-phase supplies will probably continue to expand, an increasing proportion of farm supplies will be single-phase, particularly in view of the trend towards lower apparatus loadings referred to in paragraph 395.

393. If cases should occur of private generating plant being installed as a temporary measure, we recommend that the wiring installation should conform to the requirements for mains supply so that this may be connected without difficulty when it is made available.

THE FARM LOAD AND ITS BEARING ON THE WIRING INSTALLATION

394. An investigation and survey of existing dairy and arable farms has been made, and has been of substantial advantage to us in reaching conclusions and in formulating our recommendations.

395. The majority of farm electrical appliances depend for their operation on motors or heaters of ratings 0·5 kw. to 10 kw. (*i.e.* ½ to 10 h.p. approximately). Appliances which in the past have exceeded this range of ratings are grinding mills, dairy sterilizers, and steam boilers, for which ratings up to 20 kw. have been common. In both cases, however, recent research and experimental operation have shown that equally effective results can be obtained with equipment of much lower loading. It may be expected that soon after the war grinding and sterilizing appliances having, say, only one one-quarter of the rating of those previously used may become generally available. We therefore assume that the majority of new farm appliances will not exceed 5 kw. in rating, though larger motors of, say, 10 to 20 h.p. (*i.e.* 10 to 20 kw. approximately) may be required for grain-drying or grass-drying plant, and a transportable motor of similar rating may be required for threshing or silo filling.

396. We have reached the conclusion that the heavier loads are generally grouped fairly closely together, or can be so grouped. Although electricity is essentially a flexible service which enables plant to be placed in any desired location, we recommend that where conveniently possible the main load appliances, *e.g.* for sterilizing, grinding, pulping, etc., should be grouped together so that the cost of power wiring may be minimized.

397. The following examples, taken from modern practice of applications of electricity on the farm, indicate the range of service for which an adequate electrical installation should provide:

i. MILK PRODUCTION

a. *Cowhouse*

Lighting. In a typical single range shed, lighting may be by means of ceiling fittings in a central passageway, or bulkhead fittings on the wall behind the cows.

Socket-Outlets. A number of suitably placed standard socket-outlets (see paragraph 400) for supplying hand lamps, clipping machines, etc. should be provided. These are essential if the best use is to be made of the installation.

Ventilation. A fan may be provided in the roof or gable if mechanical ventilation is required.

Power. The milking machine motor, which may be situated in the dairy, or other room adjoining the cowhouse, or, alternatively, in a milking parlour, will have a rating of ½ to 1 h.p.

b. *Dairy*

Lighting, and one or two socket-outlets for fan, bottle washers, etc. will be required.

Sterilizer	4 to 9 kw. (These ratings cover the range of requirements of herds of 20 to 40 cows.)
Water heater	1 to 3 kw.
Cooler	¾ to 2 h.p.
Water pump, if required	½ to 1 h.p.

c. *Food Store and Mixing Room*

A small hoist may be required	½ to 1 h.p.
Mixing machine	5 h.p.
Grinding mill (new type)	3 h.p.
Cake breaker	2 h.p.

Some of these machines may be situated in the barn or other buildings according to the layout of the farm.

ii. MIXED FARMING

In the case of mixed farming, but where no dairy herd is kept, provision for the following machinery may have to be made:

Grinding mill (new type)	3 h.p.
Chaff cutting, root cutting, or cake breaking	10 h.p.
Mixing machines	5 h.p.
Hoist	1 h.p.
Threshing, sawing, or power for crop dryer	10 to 20 h.p.
Water pumping	1 h.p.

In most cases it will be more convenient for each of the above machines to be fitted with its own motor, but where barn machines, such as a chaff cutter, root cutter, and cake breaker, can be fixed fairly near to each other, one motor may be used to drive all the machines by shaft and belting, without undue loss of power in friction.

Threshers, saws, elevators, silo fillers, and other machines used out of doors around the farm buildings may be driven by weatherproof motors mounted on skids or wheels for convenient handling. Such motors can be supplied by means of trailing cables from a few watertight socket-outlets fixed on the outside of farm buildings in positions chosen so that the trailing cable is not likely to lie across a roadway.

iii. POULTRY PRODUCTION

The wiring installation will be required to provide a number of 3-pin standard socket-outlets distributed throughout the buildings for the convenient connection of incubators, brooders, etc., the total load of which may be roughly estimated as follows:

Incubator room	$\frac{1}{4}$ to 1 watt per egg.
Rearing houses	$1\frac{1}{2}$ to $2\frac{1}{2}$ watts per chick.
Laying houses; lights and drinking water warmers	2 to 3 watts per bird.

LIGHTING

398. Electric lighting can of itself greatly improve working conditions and cleanliness in farm buildings, and care should be taken in planning the wiring of both new and existing premises that adequate lighting provision is made in the buildings and where necessary in the farmyard and approaches. The number and size of lamps should be arranged to provide good illumination over all working areas; for example, in a single range cowshed for twelve cows, two lights on the wall along the feeding passage and at least three lights on the wall behind the cows are advisable. Bulkhead type fittings to take 60 or 100 watt lamps are suitable for wall mounting, and should be of waterproof pattern in cowsheds and dairies. In other buildings also this type of fitting has advantages from the point of view of robustness and easy cleaning. Yard and roadway lights should be fixed as high as possible on poles or gable ends, so as to give good illumination without glare. Portable hand lamps should be of Home Office shock-proof type, as described in the Factory Regulations.

LIGHT SWITCHES

399. Economy in wiring and convenience in use is promoted by grouped switching of light circuits rather than by individual switches for each light. Two- or three-way switching should be used in buildings with more than one entrance and for outside lights. In the latter case, one switch should be provided in the farmhouse. Cord-operated ceiling switches may present advantages in certain situations, such as dairies, and will effect some economy in wiring.

GENERAL UTILITY SOCKET-OUTLETS

400. Provision should be made for the use of appliances of moderate power in all buildings. For this purpose 3-pin standard socket-outlets are recommended. These will facilitate the use of hand lamps, portable tools, and many existing small appliances and also make it generally possible to take advantage of new applications and appliances, which may reasonably be anticipated. Socket-outlet circuits would radiate from the service position through the various farm buildings. In new farms and in certain layouts of existing buildings, consideration should be given to one or more ring circuits to carry all the general utility socket-outlets.

401. Having regard to the present trend towards mechanization we consider it important that provision for the use of small electrically driven tools and for battery chargers (for vehicles and electric fences) should be made in the implements shed or workshop and in the garage.

FITTINGS AND ACCESSORIES

402. It is generally desirable that socket-outlets and plugs, lamp holders, switches, joint boxes, etc., should be of the insulated type. Also, having regard to the possibility of accidental damage in many farm situations, these fittings should be of more robust construction than is generally considered necessary for domestic purposes. Where exposed to water and moisture, fittings such as joint boxes should be filled or plugged with suitable waterproof compound.

FUSING

403. Single-pole fusing should be used in conformity with standard practice (see paragraph 34). The use of rewirable porcelain fuses should be discouraged and their place should be taken by standard enclosed cartridge-type fuses. Fuses of different ratings should not be interchangeable. The ratings should be clearly and indelibly marked on fuses, and it should be readily possible to distinguish between new and blown fuses by the appearance.

CIRCUIT BREAKERS

404. Consideration may be given to the use of quick-acting circuit breakers in place of the consumer's main switch, and possibly in place of circuit fuses.

SYSTEMS OF WIRING

405. We have considered the various wiring systems which have been used in the past in this country, in the United States, and in Europe. We are satisfied that of the systems previously used in this country none is completely satisfactory under all farm conditions; certain qualifications and reservations apply to every system.

406. We consider that the adoption of a single system of wiring for farms, which could be recognized as standard, would greatly simplify the reliable and economic electrification of farm buildings, both from the aspects of manufacture and installation.

407. A standard farm wiring system should satisfy the following main conditions:

i. The cable must be mechanically strong and resistant to ammoniacal fumes, steam, and damp.

ii. Its cost should be reasonable.

iii. Its installation should not require such a high degree of skill as to limit unduly the rate of introduction.

408. A wiring system which complies with these requirements was used to an increasing extent in pre-war years on Swedish and German farms. It uses a metal-taped insulated cable, generally similar to that covered by *B.S.* 7, and provides mechanical, chemical, and electrical protection for the conductors. Although this system would fulfil the requirements of a standard farm system, we consider that it is not to be recommended in view of the relatively high cost of continuous armouring which, however, is essential for only a small proportion of a farm installation. We estimate that the cost of an installation completed in metal-taped cable would be approximately equal to one in vulcanized rubber-insulated cable run in screwed galvanized iron conduit. Both would represent good practice, but we consider that the system recommended in the next paragraph, although less robust than either of these alternatives, provides a satisfactory and less expensive solution, which would facilitate more rapid extensions in the immediate post-war years.

409. We recommend for use as a general purpose cable, and for adoption as the basis of a standard system of farm wiring, tough rubber-sheathed cable, protected with cotton braid vulcanized on and compounded over.

410. Cable of this type is particularly suitable for the wiring of existing farm buildings which, as already stated (paragraph 385), are likely to form the major part of the post-war farm electrification programme.

411. This cable fulfils the requirements stated above except in respect of its limited mechanical protection. A high degree of mechanical protection is, however, necessary only in a limited number of locations, and here suitable protection may be provided by means of insulating conduit. Metal conduit is not recommended since, for safety reasons, it would require to be separately earthed and unless galvanized would be liable to corrosion. As regards the possibility of attack by vermin, practical experience shows the risk to be negligible, if care is taken to avoid rat runs when installing the cable.

412. Since metal-cased appliances requiring to be earthed will be used in farms, the proposed cable should contain an earth continuity conductor.

413. We consider that similar cable insulated with polyvinyl chloride (P.V.C.) would form a satisfactory alternative, to which the possibility of post-war rubber shortage gives added importance. Such cable may be expected to be generally available in the near future and may, in certain characteristics, possess better qualities than the recommended special T.R.S. cable. For example, P.V.C. cable is understood to possess exceptional resistance to damp, corrosive conditions.

414. To reduce the risk of mechanical damage and of accidental contact it is recommended that the wiring should be installed high and well out of normal reach. In dairies, cleat mounting may be used, as this permits of thorough cleansing by hosing down. Mechanical protection is recommended for down-drops to socket-outlets or for connection to appliances where these are likely to be subject to damage. Alternatively, to avoid mechanical or chemical damage it may in certain cases be practicable to run the wiring more safely on the outside of the building and to bring it in where necessary. If a motor has to be mounted on the floor some distance away from the wall on which the wiring is run, care should be taken to provide adequate mechanical protection for the wiring between the wall and the motor terminal box.

415. A permanent diagram showing the position of all cable runs should be provided at the service position.

EARTHING

416. Earthed appliances will invariably be used, and one or other of the following earthing arrangements should be made in consultation with the supply undertaking:

i. To the water-supply main where this is available.

ii. To the lead sheath, if any, of the undertaking's service cable, where this is regarded as satisfactory and acceptable by the undertaking.

iii. To an effective earth electrode or electrodes which should be subject to inspection by the supply undertaking at the time of installation, and to subsequent periodic inspections by a competent person.

iv. If the earth resistance in a locality is too high for safety to be obtained by means of direct connection to an earth electrode system, and if methods (i) and (ii) are impracticable, provision for protection may be made either by means of an earth leakage circuit breaker of appropriate rating or by means of protective multiple earthing, if this method is adopted by the supply undertaking.

SERVICE POSITION AND ACCOMMODATION

417. We recommend that the electricity service, which will generally be by overhead line, should terminate when convenient at the centre of the heavier loads. The supply control, consisting of the undertaking's main fuse and meter, also the main switch and fuses controlling the installation, should be fixed in a clean, dry, and easily accessible position. On large farms a separate small room might well be provided to accommodate this equipment. Our recommendations for consumers' supply controls in domestic premises (paragraphs 30–44) should be borne in mind in appropriate cases.

ELECTRICITY SUPPLY TO OUT-BUILDINGS AND FIELD LOCATIONS

418. To supply near-by out-buildings, the proposed special T.R.S. cable or P.V.C. cable may be slung from a catenary. For more distant buildings or field locations for hay elevating, sheep shearing, etc., a light open line should be used. In special cases consideration may also be given to the possibility of deriving a convenient supply by tapping the incoming overhead supply line to the farm.

ELECTRIC FENCES

419. Detailed consideration of electric fences has not been undertaken, since these are for field use and do not lie within the scope of the present study. Reference has, however, been made in paragraph 401 to charging facilities for the low voltage batteries from which the apparatus required derives its supply. Electrical fences are growing in popularity in this country, and it may be noted that their characteristics are being considered by the British Standards Institution.

TELECOMMUNICATIONS

420. Provision for a telephone and for radio reception will generally be made at the farmhouse. The recommendations contained in paragraphs 106 to 129 are generally applicable.

SUGGESTED INSTALLATION FOR A PROPOSED POST-WAR FARM BUILDING

421. The Farm Buildings Committee have kindly provided us with a plan of a proposed type of post-war farmstead. This is shown in Figure 11, and as a general example of the application of our present recommendations, the essential requirements of the electrical installation are marked on the plan.

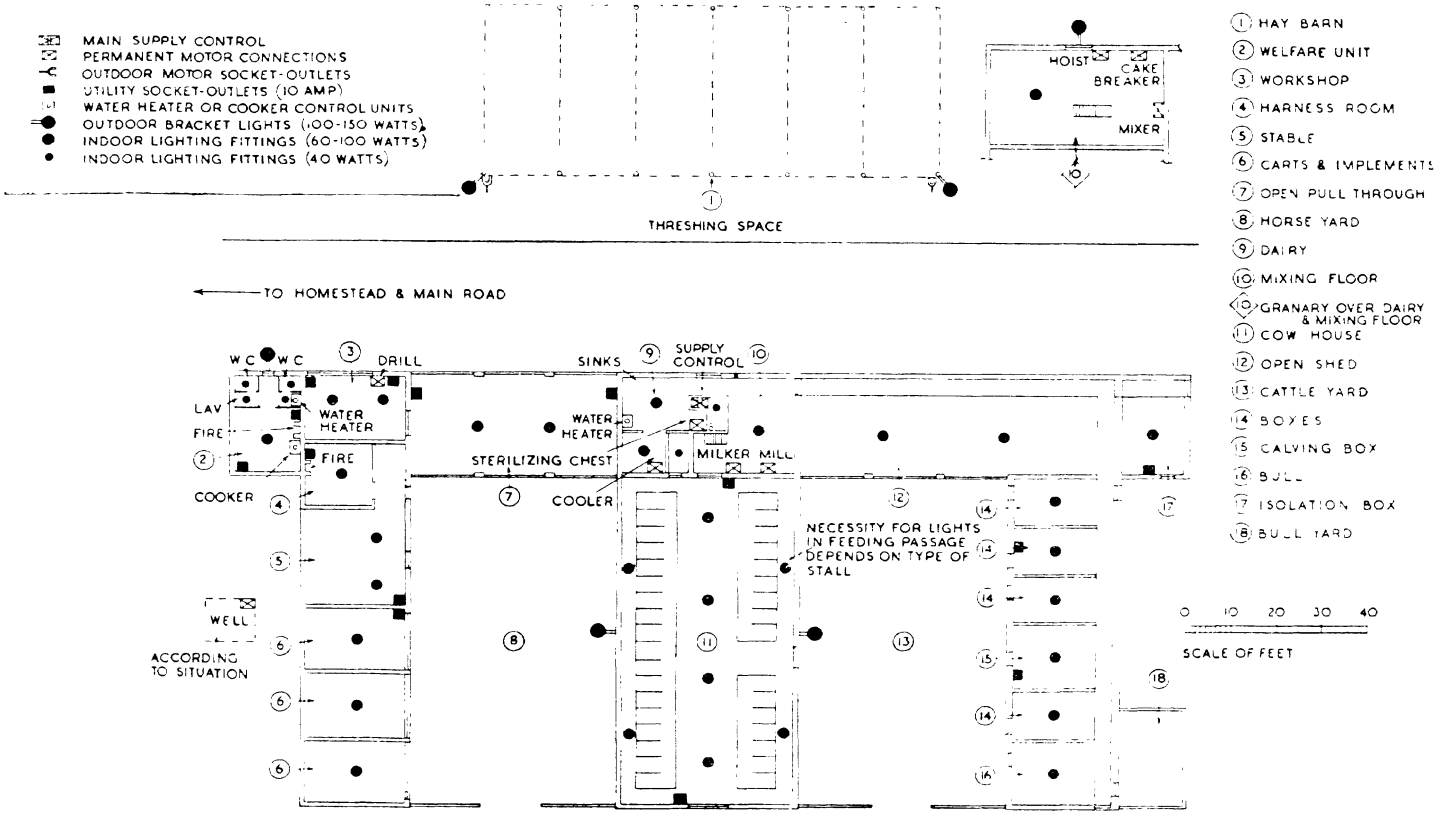


Fig. 11. SUGGESTED ELECTRICAL INSTALLATION FOR A PROPOSED POST-WAR FARM BUILDING

(See paragraph 421)

SUMMARY OF RECOMMENDATIONS

Our recommendations are summarized below. Many of the points to which we have drawn attention do not lend themselves to expression in the form of recommendations and are, therefore, not summarized.

INTRODUCTION

To ensure satisfactory installations early, full, and progressive co-operation and collaboration should take place between the architect and the engineering and other interests concerned at all stages of planning and construction.

PART I. ELECTRICITY IN HOUSES AND FLATS

Many forms of electricity supply tariff employ only one meter for each consumer, which results in an economical internal installation. We assume that such forms of tariff will be adopted throughout the country for domestic premises, and our further recommendations are based on this assumption.

SECTION I. INSTALLATIONS IN SMALL HOUSES AND FLATS

A. *Service and Control Arrangements*

The capacity of the service cable and of the consumer's supply control should anticipate possible future requirements. (Paragraph 16.)

Service entry arrangements, whether by underground or overhead, and the position of the consumer's supply control should be determined beforehand. (Paragraph 17.)

Underground Service. The cable recommended as standard is 0·0225 sq. in. twin paper-insulated, lead-sheathed, unarmoured cable, manufactured to *B.S.* 480–1942. This has a capacity of 16 kw. at 230 volts. (Paragraph 18.)

Service cables should be laid not less than 18 in. below gardens, and not less than 12 in. below paths. (Paragraph 19.)

Overhead Service. The cable recommended as standard is 0·0225 sq. in. single or twin rubber (or P.V.C.) insulated, taped, braided, weather-resisting cable. (Paragraphs 22 and 23.)

"Under-eave construction" should be used in suitable circumstances. (Paragraph 27.)

Earthing. Earthing arrangements in accordance with one of four alternatives should be made. (Paragraph 29.)

Consumer's Supply Controls. Pending the development of consumer's supply control units as recommended below, the use of the type of fitting which serves as a cable sealing box and main supply fuse box should be used. (Paragraph 32.)

Where consumer's supply control equipment of existing design is used, it should be housed in a box fitted with a door and be designed for building into a wall. (Paragraph 33.)

A consumer's supply control unit incorporating any existing designs of cable sealing box, main switch, four single-pole fuseways, and meter is described. The overall dimensions are 34 in. high by 13½ in. wide by 7½ in. deep. The standardization of a unit generally on this principle is recommended. (Paragraphs 34 and 35, and Figure 2.)

The development of a more compact supply control unit is urged. (Paragraph 36 and Figure 3.)

The positions chosen for consumer's supply control units should be well lit and readily accessible for coin insertion and meter reading. (Paragraphs 39 to 41.)

B. *Internal Installations in Small Houses and Flats*

Recommendations as to the numbers and positions of lighting points are made. In small dwellings lighting fittings complete with lamps should be supplied as part of the installation. (Paragraphs 46 to 48.)

General Domestic Applications. Socket-outlets should be provided for the use at will of radiators, lamps, radio, clocks, toaster, iron, and other small appliances. (Paragraphs 49 and 50.)

Cooking. Wiring to a suitable cooker position in each kitchen should be provided. Alternatively, conduit should be run to the cooker position so that wires may be drawn in when required. (Paragraphs 51 to 53.)

Water Heating. In addition to existing types, a new multiple unit water heater of 20-gallon capacity is advocated. Storage tanks for solid fuel fired installations should be provided with bosses for the insertion of combined heater-thermostat units. (Paragraphs 56 to 61 and Figures 9 and 10.)

Refrigeration. The provision of refrigerators of 4 cu. ft. capacity is recommended. (Paragraphs 62, 178, and 179, and Figure 7.)

Space Heating. Early consideration should be given to the thermal insulation characteristics of dwellings. The positions of inset radiant electric fires and convectors, when used, should be determined so that suitable recesses may be provided when building. (Paragraphs 64 to 66.)

Laundering. Kitchen premises should provide accommodation for wash-boiler and washing machine, and for a drying cupboard. (Paragraphs 67 to 71, and Figure 8.)

Provision of Socket-Outlets. As a general guide the following is recommended as a minimum (paragraph 72):

Living rooms:	Three standard socket-outlets.
Double bedrooms:	Three „ „ „
Single bedrooms:	Two „ „ „
Kitchen:	Three „ „ „
	And in addition, one connection for cooker, and one connection for refrigerator.
Water heater:	One connection to be provided in desired location.
Laundering:	Socket-outlets to be provided according to the laundering facilities required.

Positions of Socket-Outlets and Light Switches. Light switches should be fixed 4 ft. 6 in. above floor level. Socket-outlets should be located not less than 5 in. and preferably as high as 9 in. above floor level, except in kitchens, wash-houses, etc. where the height above floor level should be 4 ft. 6 in. (Paragraph 73.)

Switches. British Standards should be prepared to cover wall switches and cord- or chain-operated switches. (Paragraphs 74 and 75.)

Ring Circuit. In small dwellings three circuits should be provided for lighting, cooking, and socket-outlets respectively. The socket-outlets should be supplied from a ring circuit fused for 30 amperes at the consumer's supply control. Alternatively, a room circuit system may be considered. (Paragraphs 76 to 78.)

Fuses. Rewirable porcelain fuses should be abandoned in favour of standard enclosed cartridge fuses. The fuses should be of the same standard of performance as Category 3 (*B.S.* 88), and spares should be stored in the consumer's supply control. (Paragraphs 80 and 94.)

Standard Socket-Outlet and Plug. A majority of the Committee recommend that the British Standards Institution be asked to prepare a new standard specification for a 10-ampere, fused, shuttered socket-outlet and plug with round pins of spacing and dimensions conforming to *B.S.* 546. (Paragraph 92.)

A minority wish to postpone a decision until alternative designs and models of the proposed uprated 5-ampere socket-outlet and of new socket-outlets and plugs can be made available. (Paragraph 93.)

(Note : A unanimous decision has since been reached and is given in the Appendix on p. 87.)

Systems of Wiring. V.I.R. (or P.V.C.) cable run in screwed or lug-grip-jointed light gauge welded or brazed steel conduit is recommended. (Paragraph 95.)

Alternatively, a continuous wall duct at skirting level inside which electricity supply and telecommunications conduits could be run may be employed. (Paragraph 99.)

The provision of ducts throughout the building may improve the flexibility of the installation by avoiding the need for conduit. (Paragraph 100.)

Flexes of circular section should be used, and the use of flexes smaller than 23/·0076 in. should be discouraged. (Paragraph 101.)

A diagram of house cable runs should be provided. (Paragraph 102.)

Prefabrication. In prefabricated wall sections channels should be provided to facilitate wiring. (Paragraph 103.)

Central Heating. Central heating, if adopted, should provide background heat only. Small radiant electric fires should be used where higher local temperatures are required. (Paragraph 104.)

C. *Telecommunications*

Early consultation should take place to determine provisions to be made for the telecommunication services. (Paragraph 106.)

Telephones. A telephone may be required in any dwelling. Means for leading-in are described and recommendations made. (Paragraphs 108, 110, 111, 112, and 113.)

Sound Broadcasting. Arrangements for aerials, for leads-in, and for earthing are described, and recommendations made. (Paragraphs 116 to 121.)

Wire Broadcasting and Television. Lead-in means are described and recommendations made. (Paragraphs 123 to 125.)

Radio Interference. The Institution's Report on Electrical Interference with Broadcasting (July 1936) should be implemented. Metallic screening of the supply wiring may be required. (Paragraphs 126 and 127.)

SECTION 2. INSTALLATIONS IN LARGER HOUSES AND FLATS

A. *Service and Control Arrangements*

Consumer's Supply Control. A control unit with eight fuseways is recommended, or two separate units, one containing the undertaking's cable entry and main fuse, etc. and the other the eight fuses, mounted in a central position, may be used. (Paragraphs 134 to 137.)

Circuit Breakers. The use of circuit breakers should be considered. (Paragraph 139.)

B. *Internal Installations in Larger Houses and Flats*

Lighting. Decorative lighting by direct and indirect methods may supplement the recommendations of Section 1. Fluorescent lighting may offer advantages, particularly in the kitchen. (Paragraph 141.)

General Domestic Purposes. Recommendations for the provision of socket-outlets are made. In a typical "larger house" two or more ring circuits may be required. (Paragraph 142.)

Cooking, Water Heating, Refrigeration, Mixing, and Dish Washing. Certain recommendations are made. (Paragraphs 145 to 150.)

Space Heating. The recommendations of Section 1 apply. (Paragraph 151.)

Ventilation. In special circumstances fans, fan heaters, or trunked ventilation controlled by louvres may be required. (Paragraph 154.)

Laundering. A laundry or "utility room" is recommended, provided with adequate socket-outlet facilities, of which details are given. (Paragraphs 155 to 157.)

Clocks. Adequate provisions are recommended. (Paragraph 158.)

Other Electrical Requirements of the Larger House. Attention is drawn to electrical requirements for the garage, workshop, and for pumping water. (Paragraph 159.)

C. *Telecommunications in Larger Houses and Flats*

Telephones, Sound, and Television Broadcasting. The provisions for these services are discussed and suggestions for the internal installation are made. (Paragraphs 161 and 162.)

House Telephones, Door Bells, Fire Alarms, Burglar Alarms. Installations for these purposes are discussed. (Paragraphs 164, 165, 166, and 167.)

Control Point for Household Telecommunications Installation. A covered recess 9 in. by 12 in. by 3 in. deep may be required. (Paragraph 168.)

Segregation of Wiring. The circumstances in which telecommunications wiring should be segregated from electricity supply wiring are described. (Paragraph 169.)

Radio Interference. In premises where high frequency apparatus is operated an adequately screened room is required. (Paragraph 170.)

SECTION 3. ELECTRICAL DOMESTIC APPLIANCES

Cookers. Provision for "horizontal" cookers of the dimensions given in Figure 6 should be made. Vertical cookers will also be available. (Paragraphs 174 to 177.)

Refrigerators. A storage capacity of 4 cu. ft. is recommended. Overall dimensions are given. (Paragraphs 178 and 179, and Figure 7.)

Wash-Boilers. Round and square types will be available. Overall dimensions are given. (Paragraph 180.)

Washing Machines. A power-driven machine with wringer is recommended. (Paragraph 181 and Figure 8.)

Radiant Electric Fires and Electric Convectors. Dimensions should be related to the proposed standard openings of solid fuel fire-places. (Paragraphs 183 to 185.)

Water Heaters. The dimensions are given of existing types, of capacities from 1½ to 30 gallons. A 20-gallon heater installed under the sink draining board is recommended. (Paragraphs 186 and 187, and Figures 9 and 10.)

Immersion Heaters and Thermostats. Standard heater-thermostat units for fitting to a standard boss are recommended. (Paragraph 188.)

Standards of Space Heating and Water Heating. The standards recommended in the Report of the Heating and Ventilation Committee are complied with in the recommendations made. (Paragraph 189.)

PART II. OWNERSHIP AND CONTROL OF ELECTRICITY SERVICE CABLES IN BLOCKS OF FLATS AND IN OTHER MULTI-OCCUPIER BUILDINGS

To cheapen and to facilitate electricity supply to these buildings the following recommendations are made. (Paragraphs 191 to 201.)

i. Early consultation to ensure suitable provision for the accommodation of supply and telecommunication services.

ii. Provision of adequate vertical and horizontal service cables in all multi-consumer buildings during erection, to ensure full use of electricity at will by the tenants.

iii. The supply undertaking to specify minimum sizes of service cables, agreement being reached with the building owner.

iv. The supply undertaking to own, control, and maintain the service cables, and to increase their capacity when necessary.

v. The supply undertaking to bear the whole or part of the cost of the service cables, as they would for service cables to equivalent houses.

vi. Retailing by landlord of supply purchased in bulk to be discouraged.

PART III. ELECTRICITY IN MULTI-OCCUPIER AND SIMILAR BUILDINGS, BLOCKS OF FLATS, OFFICES AND ADMINISTRATIVE BUILDINGS, DEPARTMENT STORES AND HOTELS

Early consultation to ensure the provision of adequate electrical and telecommunications installations is recommended. (Paragraph 205.)

Installation arrangements should provide for known demands and probable future demands. (Paragraphs 206 to 208.)

Final plans, prior to commencement of work, should show the provisions to be made for all services. (Paragraph 208.)

SECTION I. COMMON REQUIREMENTS OF INSTALLATIONS IN MULTI-OCCUPIER AND SIMILAR BUILDINGS

Electricity Supply Intake. Provision should be made for a 3-phase, 4-wire, 400/230 volt 50-cycle A.C. electricity service derived directly from low tension mains, or from a transformer installed in the building. (Paragraph 211.)

SUMMARY OF RECOMMENDATIONS

Common Services. Recommendations made in the report of the Mechanical Installations Committee should be followed. (Paragraph 212.)

Vertical Ducts. Rising conductors should be run in accessible ducts reserved for this purpose. In small buildings one duct may supply each floor. In large buildings one duct per 5000 sq. ft. of ground floor area may be necessary. (Paragraphs 213 and 214.)

In large buildings the vertical ducts should be not less than 36 in. by 9 in. in cross-section. In small buildings ducts should be not less than 18 in. by 6 in. in cross-section. Precautions against fire transmission through ducts must be taken. (Paragraph 215.)

Rising Conductors. Bare conductors are recommended but, alternatively, suitable cables may be used. (Paragraph 216.)

Lift Shafts. Lift shafts should not be used for rising conductors. (Paragraph 217.)

Horizontal Runs. In buildings with corridors, cables or conduits may be run in floor ducts or hollow ceilings. To serve permanent outlet positions the use of V.I.R. (or P.V.C.) cable run in screwed or lug-grip-jointed welded or brazed steel conduit placed in the floor either on the shuttering or in screeding of suitable depth, or between floor blocks, is recommended. (Paragraphs 218 and 219.)

Where a flexible installation is essential, a hollow wooden floor or its equivalent to house a conduit "grid" is recommended. In solid floors, architectural consideration should be given to a "grid" of floor channels. Failing these provisions the installation should be carried out in conduit. (Paragraphs 220 to 223.)

Installation Diagram. A diagram of all cable ways and cables should be available, and should be kept up to date. (Paragraph 224.)

Identification. Ducts, conduits, and cables should be identified in accordance with the relevant British Standard. (Paragraph 225.)

Lighting. Stair, corridor, and entrance lighting should be installed. Emergency lighting may be required. (Paragraphs 227 and 228.)

Space Heating. Methods of direct electric space heating are described. (Paragraph 229.)

Temperature Control. Climate-sensitive control apparatus outside a building, or local thermostatic controls inside, are discussed. (Paragraphs 230 and 231.)

Composition Floors. In these, metal conduits should be protected from corrosion, or fibre conduits should be used. (Paragraph 233.)

Relations to other Services. A transformer substation or control room should contain electrical equipment only. Contact between cables or conduits and other metal pipes, etc. should be prevented. (Paragraph 234.)

Lightning. Lightning conductors should be provided in accordance with Code of Practice C.P.1. 1943. (Paragraph 237.)

SECTION 2. SPECIAL REQUIREMENTS OF INSTALLATIONS IN BLOCKS OF FLATS

Distribution at each Storey. Each vertical duct should enter a sealed distribution board on each storey provided with single-pole fuses for the number of services required. Conduits should be run to the individual consumers' supply controls. (Paragraphs 239 to 241.)

SECTION 3. SPECIAL REQUIREMENTS OF INSTALLATIONS IN OFFICES AND ADMINISTRATIVE BUILDINGS

Socket-Outlets. Socket-outlets and plugs (paragraphs 92 and 93) supplied from the floor installation and located on walls and stanchions at, say, 9 in. above floor level, are recommended. Water-tight floor socket-outlets should be provided, if required. (Paragraph 246.)

Lighting. Reference should be made to the Report of the Lighting Committee. Fluorescent lighting should be considered. The switching of lights in zones is recommended. (Paragraphs 248 to 253.)

SECTION 4. SPECIAL REQUIREMENTS OF INSTALLATIONS IN DEPARTMENT STORES

Socket-Outlets. Liberal provision of standard socket-outlets is recommended. These should be located mainly on stanchions, but floor outlets may also be required. (Paragraph 259.)

Lighting. Reference should be made to the Report of the Lighting Committee. Fluorescent lighting is particularly applicable. Provision for advertising display and flood lighting should be considered when designing a building so that disfigurement may be avoided. (Paragraphs 260 to 266.)

SECTION 5. SPECIAL REQUIREMENTS OF INSTALLATIONS IN HOTELS

Bedroom Lighting. Lighting should be provided for the dressing table, at the wash-hand basin, and at a bedside position. (Paragraph 268.)

Bedroom Socket-Outlets. At least two standard socket-outlets should be installed in every bedroom for the use of visitors' appliances, and for cleaning equipment. (Paragraph 269.)

Electric Locks. Electric room locks controlled by bedside switches may be considered. (Paragraph 270.)

Space Heating. A radiant electric fire or convector may be provided for supplementary heating. (Paragraph 271.)

Socket-Outlets in Public Rooms, Staff Rooms, and Corridors. Adequate numbers for the use of portable appliances, radio sets, vacuum cleaning equipment, etc., spaced not more than 30 ft. apart, are recommended. (Paragraph 272.)

Guests' Laundering. Provision of a room equipped with a drying cupboard, electric irons, and other small laundering facilities should be considered. (Paragraph 273.)

SECTION 6. TELECOMMUNICATIONS IN MULTI-OCCUPIER AND SIMILAR BUILDINGS

A. *Common Telecommunications Service Installations in Blocks of Flats*

Private Branch Exchanges. Consultation should take place to determine the provision necessary. (Paragraph 275.)

Public Call Offices. These should be incorporated as built-in features in entrance halls, etc. (Paragraph 276.)

Sound Broadcast Programmes. Broadcast programmes may be distributed to individual flats by one of several systems which are described. (Paragraph 277.)

Television. Space should be reserved for television equipment. (Paragraph 278.)

Bells, Clocks, and Fire Alarms. Installation requirements are discussed. (Paragraphs 279, 280, and 281.)

Provision for Wiring

Leading-in. Means for leading-in are described and recommendations made (Paragraphs 282 to 285.)

Controls. A control room for communication services may be necessary (Paragraph 286.)

Vertical Ducts. Separate vertical ducts should be provided for telecommunication services, but larger ducts may be shared if segregation is observed (Paragraph 288.)

Horizontal Runs. Means for effecting horizontal runs are described and recommendations made. (Paragraphs 289 and 290.)

Conduits. Segregation of telecommunication services is discussed and recommendations made. (Paragraph 291.)

B. *Telecommunications Service Installations in other Large Buildings, including Offices and Administrative Buildings, Department Stores and Hotels*

i. *General Requirements*

Adequate provision must be made for flexibility and future expansion. (Paragraphs 294 and 295.)

Telephone Services. Alternatives are described. (Paragraphs 298 to 300.)

Standard Switchboards. Provision for these must be made. A separate apparatus room and a separate battery room may be required. (Paragraphs 298 to 300.)

Telegraph Services. Requirements are discussed and recommendations made. (Paragraphs 302 to 304.)

Sound and Television Broadcasting. Requirements are described and recommendations made. (Paragraphs 305 to 307.)

ii. *Other Telecommunication Services in Large Buildings*

Staff Locating Systems, Public Address Systems, Service Call Systems, Bells, Clocks, Fire and Burglar Alarms. Installation requirements of these services are discussed. (Paragraphs 309 to 318.)

iii. *Provision for Wiring*

Extensions and modifications must be catered for. (Paragraphs 321 and 324.)

Radio Interference. Special attention should be given to the screening of rooms or workshops in which high frequency apparatus is to be used. (Paragraph 326.)

PART IV. ELECTRICITY IN SCHOOLS

SECTION 1. ELECTRICAL INSTALLATIONS

Recommendations applicable to schools are made, particularly to the single storey modern school for 360 children provisionally planned by the School Building Committee. (Paragraphs 327 to 331.)

Electricity Supply Intake. A suitable space for intake apparatus and switchgear should be provided near the centre of load. (Paragraphs 332 and 333.)

Wiring System. The use of V.I.R. (or P.V.C.) cable run in screwed or lug-grip-jointed welded or brazed steel conduit is recommended. (Paragraph 334.)

Layout of Wiring. Accommodation for the main wiring runs in false ceilings in the flat-roofed interconnecting corridors is recommended. (Paragraph 335.)

Prefabrication. Prefabricated wall panels, if used, should have at least one vertical channel in each, to facilitate wiring. (Paragraph 336.)

Lighting. Reference should be made to the Report of the Lighting Committee. (Paragraph 337.)

Space Heating. Main space heating can be effected by electricity when desired. Local heating appliances may be required in certain rooms. (Paragraph 338.)

Educational Equipment. Adequate socket-outlets, etc. should be provided in domestic science rooms and in handcraft workshops. (Paragraph 339.)

Clothes Drying Rooms. Suitable heaters or fan heaters are described. (Paragraph 340.)

Hand Washing and Drying. The use of electric hand dryers should be considered. (Paragraphs 341 and 342.)

School Meals. Electric cookers, urns, mixers, etc. may be required. (Paragraph 343.)

Outbuildings, Playground Lighting, etc. To avoid later disturbance, ducts should be run under asphalt playgrounds. (Paragraph 344.)

Safety Considerations. Standard socket-outlets and concealed or flush-mounted fittings are recommended. (Paragraph 345.)

SECTION 2. TELECOMMUNICATIONS IN SCHOOLS

Telephone Service depending on the type of school will be required. (Paragraph 346.)

Sound and Television Broadcasting. Reception facilities should be provided. (Paragraph 347.)

Bells, Clocks, Fire Alarms. General recommendations are made. (Paragraphs 350 to 352.)

Provision for Wiring. The installation requirements of the telecommunication services are indicated. (Paragraphs 353 to 356.)

PART V. ELECTRICITY IN HOSPITALS

Electricity Supply Intake. Recommendations are made regarding intake arrangements. (Paragraphs 364 and 365.)

Vertical and Horizontal Installation. The special requirements of hospital installations are briefly reviewed. (Paragraphs 368 and 369.)

Bedside Panels and Socket-Outlets. A small wall panel should be provided at each bed position. (Paragraph 370.)

Lighting. Reference is made to the lighting of wards and operating theatres. (Paragraphs 371 to 374.)

Space Heating. Reference is made to the use of electricity for space heating. (Paragraphs 375 and 376.)

X-ray Apparatus. Supply cables of adequate capacity should be used, and automatic voltage regulation may be necessary. (Paragraph 378.)

Operating Theatres. Reference is made to certain special requirements and to safety measures. (Paragraphs 379 and 380.)

Telecommunications Services. Provision for telephone service is described. Headphones should be provided for the reception of broadcast programmes by patients. (Paragraphs 381 and 382.)

PART VI. ELECTRICITY IN FARM BUILDINGS

Post-War Farm Building and Electrification. Early consultation between farmer, architect and/or builder, and engineer should take place. (Paragraph 387.)

The influence of mechanized methods on the design of farm buildings should be considered. (Paragraph 388.)

Reference is made to the need for improved amenities for both farming and domestic work. (Paragraphs 389 and 390.)

Water Supply. In the absence of a public water supply an electrically pumped supply may give the same convenience. (Paragraph 391.)

Farm Load. Electrical apparatus may be placed in any required location, but the main load appliances should generally be grouped together to reduce power-wiring costs. (Paragraphs 395 and 396.)

Examples of Modern Electrical Practice on Farms. The requirements of a mixed farm, of a dairy farm, and of a poultry farm are indicated. (Paragraph 397.)

Lighting. Attention is drawn to the effect of good lighting in improving working conditions and cleanliness, and recommendations are made. (Paragraph 398.)

Socket-Outlets. Socket-outlets should be provided for the use of small appliances in all buildings. (Paragraph 400.)

Fusing. Single-pole fuses of the cartridge type should be used. (Paragraph 403.)

Circuit Breakers. The use of circuit breakers in place of the consumer's main switch or in place of circuit fuses may be considered. (Paragraph 404.)

System of Wiring. It is recommended that tough rubber-sheathed (or P.V.C.) cable protected with cotton braid vulcanized on and compounded over, be used. (Paragraphs 405 to 414.)

Earthing. Earthing arrangements in accordance with one of four alternatives should be made. (Paragraph 416.)

Installation for a proposed Post-War Farm Building. A plan prepared by the Farm Buildings Committee of a proposed post-war farmstead is shown in Figure 11, which also shows the requirements of an electric installation in accordance with our recommendations. (Paragraph 421.)

JAMES R. BEARD, *Chairman.*
J. AUSTEN BENT.
J. I. BERNARD.
CAROLINE HASLETT.
P. V. HUNTER.
FORBES JACKSON.
W. J. JONES.
J. M. KENNEDY.
H. MARRYAT.
S. E. MONKHOUSE.
H. G. S. PECK.
A. G. RAMSEY.
E. A. REYNOLDS.
RICHARD SHEPPARD.
JAS. TOWNLEY.
R. A. URE.
W. H. WALTON.
V. WATLINGTON.
E. B. WEDMORE.
J. FLOOD.

BIBLIOGRAPHY

GENERAL

Regulations for the Electrical Equipment of Buildings, Institution of Electrical Engineers.

British Standard Code of Practice *B.S.* 1043, *The Provision of Engineering and Utility Services in Buildings.*

British Standard Code of Practice C.P.1. 1943, *Recommendations for the Protection of Structures against Lightning.*

Handbook of Interior Wiring Design, Industry Committee on Interior Wiring Design, New York (1937).

Memorandum on Safety in Operating Theatres and Anaesthetic Rooms, *Journal of The Institution of Electrical Engineers*, 1944, 91, Part I.

TELECOMMUNICATIONS

Facilities for Telephones in New Buildings, General Post Office, 1931.

Electrical Services in Large Buildings, by C. G. A. McDonald and F. C. Carter, B.Sc.(Eng.), A.M.I.E.E. (The Post Office Electrical Engineer's Journal, October, 1938).

Services in a Modern P.O. Building, by R. S. Phillips (Post Office Electrical Engineer's Journal, October, 1941.)

Partition Flexibility at Murray Hill, Bell Laboratories Record, September, 1942.

Radio Reception in Flats, Report of the Science Standing Committee of the Royal Institute of British Architects.

RADIO INTERFERENCE

Report of The Institution of Electrical Engineers' Committee on Electrical Interference with Broadcasting (1936).

Post Office Engineering Instruction on Radio Interference (Post Office Ref. C. 1101).

B.S. 800–1939, Limits of Radio Interference (and definition of " Radio Interference Free ").

B.S. 613–1935, Components for Radio Interference Suppression Devices.

B.S. 727–1937, Apparatus for the Measurement of Radio Interference.

B.S. 905–1940, Anti-interference characteristics and performance of radio receiving equipment.

APPENDIX

ELECTRICITY IN AGRICULTURE

A Critical Study of the Application of Electricity to Agriculture and to Horticulture, by C. A. Cameron Brown, B.Sc., A.M.I.E.E., British Electrical and Allied Industries Research Association Technical Report W/T2–1940.

Discussion on Electricity in Agriculture, based mainly on the above Critical Study. (Journal of the Institution of Electrical Engineers, June 1941, Part II, page 141).

Advice to Farmers on Installing Electricity, by H. D. Phelps, A.M.I.E.E., British Electrical Development Association, publication E.D.A. 1300–1935.

Farm Wiring Bulletin of the Institute for Research in Agricultural Engineering. University of Oxford, 1935.

Wiring the Farmstead (Bulletin 63 revised, May 1938). Kansas State College of Agriculture and Applied Science Extensions Service, Manhattan, Kansas.

APPENDIX

SUPPLEMENTARY REPORT ON A RECOMMENDED NEW STANDARD SOCKET-OUTLET AND PLUG

1. In our Report on Electrical Installations, which we submitted in January, 1944, we discussed at some length the problems associated with the provision of a standard " all purpose " socket-outlet and plug for domestic purposes. Majority and minority views as to the best solution of the problem were given in the Report (paragraphs 92 and 93).

2. Since January, 1944, we have continued our investigations with a view to reaching a definite decision which, while being acceptable to the technical interests concerned, would provide the consumer with a convenient and safe all-purpose plug at reasonable cost.

3. In pursuance of this investigation a " Questionary and Review of the conditions affecting the design and adoption of one form of Socket-Outlet and Plug as a National Standard " was recently sent to all supply undertakings in Great Britain and Northern Ireland. Replies have been received from some 360 undertakings who supply approximately 90 per cent of the domestic consumers of the country. An analysis of the replies to our questions has been of substantial assistance to us in reaching a conclusion.

4. Having regard to all the evidence considered by the Committee, and to the consensus of opinion evinced by the Questionary, and bearing in mind the assumption contained in our Report that tariffs necessitating only one meter will be available throughout the country, we have reached the unanimous conclusion that a completely new type of 3 kw. (230 v.) socket-outlet and fused plug should be adopted as the " all-purpose " domestic standard.

5. We consider that the design of a socket-outlet and plug in conformity with our conclusion is primarily a matter for the manufacturers, and we have therefore invited the B.E.A.M.A. to proceed as a matter of urgency with the preparation of suitable designs, which will form the subject of joint discussions with them prior to the submission of a request to the British Standards Institution for the preparation of an agreed standard. This invitation has been accepted.

6. In the course of our examination of this whole problem, a number of points of technical detail affecting the design of an " all-purpose " socket-outlet and plug were noted, and were listed in paragraph 84 of our Report. For convenience these are recapitulated below, together with several new points more recently made :

i. To ensure safety, particularly of young children, the live contacts of the socket-outlet should be protected.

ii. The design of socket-outlets and plugs should preclude " overhang " danger, *e.g.* it should not be possible to insert incorrectly one pin of the plug into the live contact tube of the socket and thus expose a live pin of the plug.

iii. To reduce the liability to damage, socket-outlets in all new installations should be of the flush-mounted or semi-recessed types.

iv. Plugs should be easy to withdraw and should be as light and compact as possible.

v. On A.C. circuits, which we have assumed will be universal in new buildings, disconnection can be safely made by withdrawing the plug; the expense and complication of a separate switch is therefore unnecessary in the standard design. It may, however, be desirable to have an alternative standard design incorporating a switch for use where this additional convenience is required.

vi. The socket-outlet connection terminals shall accommodate a 7/·029 in. cable looped in and out, and also a "spur" connection if required, *i.e.* three 7/·029 in. cables require to be accommodated. Particular attention should be given to the size of the terminals and cable anchorages in both the socket-outlet and the plug.

vii. In view of our recommendation that socket-outlets should be placed well above floor level, the plug should be standardized with the flexible connection entry at the bottom.

viii. Resilient members of the combination should be incorporated in the socket-outlet.

ix. If solid pins are used they should not be slotted.

x. Provision should be made in the plug for the accommodation of a cartridge type of fuse for 13 amps., and alternatively, for 3 amps. Fuses of these ratings should be interchangeable and be readily identified.

xi. In deciding pin spacing, consideration should be given to a radical rearrangement of the pins, *e.g.* the live pin might be in the centre with earth and neutral pins on the outside, or possibly the earth and neutral pins might be placed very close together.

xii. It is desirable, if possible, that the new standard socket-outlet should fit into an existing standard type of connecting box.

xiii. The plug should accommodate satisfactorily flexible cords of circular cross section of either size 23/·0076 in. or size 70/·0076 in.

Before taking a decision on the merits of round or flat pins for the new "all-purpose" socket-outlet we wish to have the considered views of the manufacturers to advise us on the technical and economic considerations involved in production.

Signed on behalf of the Committee,

JAMES R. BEARD,
Chairman.

July, 1944.

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The references are to paragraphs.

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TERMS OF REFERENCE

1. To review existing information and practice concerning installations in buildings for:
   a. the supply of electricity for all purposes from the point of entry of the current at the property boundary to the point of its delivery to an appliance;
   b. electrical household appliances serving the single family dwelling; and
   c. all forms of electrically operated telecommunications.
2. To review proposals for improved electrical appliances for space heating, cooking, refrigeration, hot-water supply, dish washing, and clothes washing.
3. To make recommendations for practice in post-war building.

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By a Committee appointed by the Secretary of State for Scotland.

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POST-WAR BUILDING STUDIES

NO. 14

SOUND INSULATION AND ACOUSTICS

BY

THE ACOUSTICS COMMITTEE

OF THE BUILDING RESEARCH BOARD

OF THE DEPARTMENT OF

SCIENTIFIC & INDUSTRIAL RESEARCH



LONDON: 1944

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The series of Reports being published under the title of Post-War Building Studies owes its origin to a desire expressed by professional and other institutions connected with the building and civil engineering industries to assist and support the Ministry of Works in regard to post-war plans. During the latter part of 1941 the then Minister, in order to take advantage of these offers of assistance which he was receiving from all quarters, encouraged the establishment of a series of Committees to investigate and report on the major problems which were likely to affect peace-time building. He also offered, on behalf of the Ministry, to provide the necessary staff and organization to co-ordinate the various inquiries, in such a way as to avoid duplication of effort and to secure so far as possible uniform direction and policy.

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The Committees were either appointed by a Government Department or convened by a professional institution, a research association or a trade federation, as seemed most appropriate in each case; they were so constituted as to ensure that the Reports contain the considered views of experts and others closely concerned with the subject. The Minister gratefully acknowledges the work of the Committees and the valuable assistance given both by the various convening bodies and by the individual members. The Reports are not official publications in the sense that the Government as such is responsible for or necessarily accepts the views expressed, but their contents are authoritative and cannot but be of great value to all concerned with preparations for building after the war.

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DEPARTMENT OF SCIENTIFIC AND INDUSTRIAL RESEARCH

COMMITTEE ON SOUND INSULATION AND ACOUSTICS OF BUILDINGS

To the Building Research Board

GENTLEMEN, We, the Committee appointed by you in December 1942, to consider Sound Insulation and Acoustics of Buildings, beg leave to present our Report.

Our terms of reference were as follows:

i. To review existing scientific information and practice in this country and abroad on the sound insulation and acoustics of buildings.

ii. To make recommendations for practice in post-war buildings.

iii. To make such recommendations for further research as may suggest themselves in considering (i) and (ii).

We have held five meetings, during which we have considered the existing information on sound insulation and acoustics. Our attention has been drawn to the fact that there may be special conditions which apply to practice in Scotland, and this has been kept in mind during our work.

EVIDENCE RECEIVED

We have received evidence from the Society of Women Housing Managers and from the Honorary Secretary of the Noise Abatement League. In addition, we have received from the Ministry of Works a paper on planning in relation to sound insulation by D. D. Harrison, Esq., A.R.I.B.A., and from an informal committee of musicians, information regarding the special needs of teachers and students of music and associated matters. We are grateful for this valuable help, which was willingly given to us.

We wish also to express our appreciation of the help we have received in our work from the officers of the Department. The secretarial work was carried out by Mr. William Allen of the Building Research Station, and he rendered invaluable assistance in the preparation of our Report. Mr. W. F. Higgins and Mr. N. Fleming of the National Physical Laboratory also were associated with us throughout our inquiry, and their contributions have been of great help to us in our discussions of the different problems involved.

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SOUND INSULATION AND ACOUSTICS OF BUILDINGS

A REPORT BY THE ACOUSTICS COMMITTEE OF THE
BUILDING RESEARCH BOARD OF THE
DEPARTMENT OF SCIENTIFIC AND INDUSTRIAL RESEARCH

INTRODUCTION

GENERAL POSITION IN SOUND INSULATION AND ACOUSTICS TO-DAY

1. Sound insulation and acoustics of auditoria are separate subjects, and this should be emphasized because there is a tendency to confuse not only the terms, but also the treatment of the problems. Sound insulation is concerned with the insulation of buildings, or the different parts of them, from noise generated either within or without. The term "acoustics," on the other hand, refers in building practice mainly to hearing conditions in auditoria.

2. Among the basic requirements of buildings, that of sound insulation now occupies an exceptional position because, while with other requirements changes in recent years have been for the better, with sound insulation they have been for the worse. Buildings are better heated and lighted than they were years ago, and there is better protection from such troubles as dampness; but they are noisier now.

Aggravation of the nuisance is found in two causes; on the one hand, noise sources have increased in number and strength—in the office, for instance, there is the extension of mechanical equipment, and in the home, the wireless. On the other hand, the trend of modern construction is towards a greater continuity, lightness, and engineering efficiency, which leads to the easier transmission of sound. Examples of the nuisance come to mind readily. How many unfortunate flat dwellers, for instance, find themselves disturbed by the noise of their neighbours' wireless, or of children playing on approach balconies, or of traffic? How many have to restrict their own activities for fear of disturbing others? And who amongst us has not, on some occasion or other, in an hotel found it difficult to get to sleep because of the fellow on the floor above, or the noise of the plumbing, or of people in the corridor? The examples can be multiplied indefinitely, and aggregate to a very substantial problem. We must clearly try to arrest any tendency to further deterioration in the immediate post-war building and achieve, if we can, some more suitable standards of quiet. From our Report it will be seen that research has yielded much of the information which was needed; the next step is wide application.

Cost, of course, always enters as a factor in the designer's mind. Some of the most important of our proposals for structural insulation have already been tried and found to involve little or no extra cost, and we are confident that familiarity with the others will show that they, too, are reasonable, especially if planning is also allowed to play an effective part in design for quiet.

3. Auditorium acoustics form a problem of different character, without the immediate social significance of sound insulation, but having fundamental importance in the functioning of many modern building types. Fortunately there has been some improvement in acoustic treatments in recent years, though failures are still needlessly frequent and bad hearing in lecture rooms, law courts, committee rooms, and concert halls is still a matter of common conversation.

THE SCOPE OF THE REPORT

4. We are required by the first of our terms of reference to review the present state of knowledge on sound insulation and acoustics. This has been done, and an outline of the information available is embodied in the Report. In both fields the principal factors are now well understood, and the information given should provide for all the day-to-day needs of designers and builders.

5. The second of our terms of reference requires us to make recommendations for practice in post-war building.

6. In the field of sound insulation we have devoted attention mainly to dwellings, schools, and offices.

7. In dwellings, most of the noise of which complaint is made comes from a neighbouring dwelling, and broadly speaking, people seem to accept a lesser degree of insulation within their own homes. We are in a position now to recommend suitable standards of insulation, both between and within dwellings, and to outline treatments, both of planning and structure, by which the proposed standards may be reached.

8. With schools the most important point seems generally to be the segregation of the noisy and quiet parts of the buildings on the site, though in urban districts the choice of the site itself is a big factor. A site on which classrooms would have to face directly on to a street carrying heavy traffic is unsatisfactory because only elaborate window treatments and artificial ventilation can render the rooms acceptable for teaching. Structural insulation is not unimportant, of course.

Along with schools should be bracketed a number of other community buildings, such as clinics, maternity homes, and nursery schools, in all of which the choice of a quiet site, as well as adequate structural insulation, is important. We have not discussed all these types in detail, but no difficulty should be found in devising suitable treatments based on the general information which is given.

9. Offices in crowded urban districts present a difficult problem. At present, buildings are generally taken to the street line where the noise is worst. This position is almost inevitable when individual plots are developed separately and at different times. Height restrictions support this tendency, for the buildings have to spread laterally to obtain the desired accommodation. Some insulation from street noise is obtainable by fairly elaborate window treatments, but the basic solution, and the one which would provide the most general benefits, lies in making it possible to set buildings well back from the street line, so that there is much more distance between the source of noise and the windows. This will only become practicable when the re-development of land in urban areas can be viewed as a whole, and it emphasizes the general desirability of this aim from the point of view of quiet in urban buildings. If streets, by this means, take on a more open character, they too should become quieter.

10. In the field of auditorium acoustics we have considered the specific requirements of various types of hall and made suggestions for their treatment. In particular, we emphasize the importance of having a good standard of hearing in all rooms used for teaching.

11. We have not been able to consider the problem of noise and industrial health, where much work remains to be done, or the special needs of electrical sound reproduction in auditoria.

12. In accordance with the last of our terms of reference we have made recommendations for further research.

ARRANGEMENT OF THE REPORT

13. Our Report is divided into four parts and six appendices, as follows:

Part I. Sound Insulation (town planning, site development, and structural measures).

Part II. Acoustics of Auditoria.

Part III. Proposals for future Research.

Part IV. A summary of Recommendations, Standards, and Treatments for Sound Insulation and Acoustics.

Appendices: i. Noise in plumbing, ii. Sound Transmission through Timber Floors, iii. Sound Transmission through Concrete Floors, iv. Graphical Analysis of Reflection in Auditoria, v. Measurement of Sound Absorption and Sound Insulation, vi. The Reduction of Noise through Open Windows.

PART I. SOUND INSULATION

14. Sound insulation in buildings is conveniently discussed under two headings —the exclusion of outdoor noise, and the transmission of sound inside buildings. In both cases the same order of treatment will be adopted in the Report; typical noise sources and their loudness will come first, then the methods of transmission and insulation, and finally, the desirable standards of quiet. Numerical values of noise levels will be used so far as possible, not so much because design to this degree of accuracy is an aim at present as that it is the best way of comparing the importance of different factors. That should be clearly understood. At the same time it must be noted also that these data come from several sources, measured under different conditions, and possibly with less accurate instruments than are now used, so the numerical values shown may be at best a rough guide. In our suggestions for future research we have included a programme of field measurements to provide further information about the loudness of different sources of noise.

OUTDOOR NOISE GENERALLY

SOURCES OF OUTDOOR NOISE

15. The important sources of outdoor noise are found in industry, sport, and transport.

16. In industry, some examples are steel fabrication, boiler making, power-saws, hammers, and punches. A special cause of complaint is the milk-distribution centre in residential areas, where the noise of loading and handling large tins occurs very early in the morning. Music in factories also may escape and be an annoyance in neighbouring homes.

17. Instances of noise from outdoor sporting grounds are familiar. Sometimes it may be the noise of the sport itself, as in the case of dirt-track racing, or the shouting of children in school-playgrounds. It may be the crowds of excited spectators, as at professional matches and race meets. The noises usually occur only at intervals, but nevertheless give rise to irritation among people living near by, especially if the sports are carried on late in the evening. The trend to illuminate playgrounds will probably increase the amount of night play.

18. Transport noise is a widespread cause of complaint. On the roads it arises chiefly from trams and heavy traffic, and is generally worst at main cross-roads

and traffic lights where cars have to stop and start. Railways cause annoyance—often severe in towns, especially near main-line routes and goods yards, where night work goes on. Metal viaducts often add to the noise. Air transport has a number of serious problems for some of which effective solutions are not yet in sight.

19. Except for street traffic, there have been too few measurements of outdoor noise to enable generalizations about their loudness to be made. All we can do, therefore, is to call attention to their importance, while urging an adequate programme of field measurements. (See Part III.)

LOUDNESS OF OUTDOOR NOISE

20. Traffic noise can to some extent be classified according to the type of street. Traffic authorities and town planners now classify streets according to the purpose they are intended to serve. Tripp[1] has suggested three main classes: (*a*) the arterial route, to be used for high-speed long-distance traffic only; (*b*) the sub-arterial route, carrying heavy city traffic and connecting webs of local roads to one another and to the arterial routes; and (*c*) the local roads, for residential and shopping use, but not for through traffic. These are already recognizable as types in any town, but no doubt they will emerge more distinctly as planners rationalize the street layouts.

From the point of view of a designer who wishes to ensure adequate quiet in his buildings, it is a great convenience to be able to associate with each street type a definite representative noise level, and the classification outlined is one which can conveniently be adopted for the purpose. Approximate values are suggested in Table I. These should be confirmed as soon as possible by adequate measurement. In the Table, local roads have been subdivided for shopping and for residential use; the latter may not require a fixed value, since traffic will be only incidental.

TABLE I. EQUIVALENT LOUDNESS OF OUTDOOR NOISE

TYPE OF NOISE OR LOCALITY	EQUIVALENT LOUDNESS (PHONS) [2]
Threshold of painful sound	130
Roads [3]	
Arterial roads	100
Sub-arterial roads	90
Local road (shopping)	70
Local road (residential)	40
Some Typical Noises and Values	
Aero-engine, 20 ft. distant	120
Pneumatic drill, 10 ft. distant	100
Tram	90
Motor-bus (inside noise)	70
Quiet suburban garden	30

[1] Tripp, H. A., *Town Planning and Road Traffic.*

[2] There are two units of noise measurement, the phon and the decibel, both of which are required to state the results of measurement, but both of which, for the purposes of the layman, can often be considered almost as equivalents over a fairly wide range of frequencies, and they will be so considered here unless otherwise noted. Five phons or five decibels is about the minimum change, either deterioration or improvement, which is significant in practice. A description of the units of measurement will be found in Appendix V.

[3] These values represent loudness at the kerb.

THE TRANSMISSION OF OUTDOOR NOISE

21. Having considered the loudness of sources of outdoor noise, the next stage is to examine how sound is transmitted outdoors and the extent to which its loudness can be reduced between the source and building.

Noise generated in the open air travels outward from a point source in a spherical and continuously extending wave front. Since the sound energy is thus being spread over a greater area, there must be a progressive reduction in intensity as the distance from the source increases. This can be calculated to be 6 db. every time the distance from the source is doubled. The curve on Fig. 1 shows this

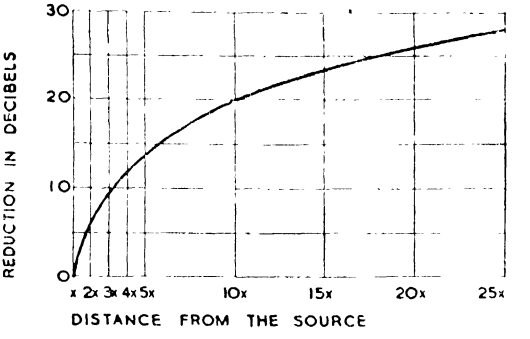


Fig. 1. GRAPH SHOWING RELATION BETWEEN SOUND REDUCTION AND DISTANCE FROM A POINT SOURCE OF NOISE

relation between sound reduction and the distance from a point source, and its use may be illustrated by an example. Suppose that the noise from an auto-bus is known to be 90 db. at the side of the street, and that the bus is in the main stream of traffic 20 ft. away. The distance 20 ft. will then be "x" on the horizontal scale of the curve. If it then is desired to know what the reduction will be, say, 70 ft. away, this may be read from the curve as being the reduction at $\frac{70}{20}$, or 3·5 times x, the original distance. The reduction itself is shown on the vertical scale, and is about 10 db. Finally, then, the intensity 70 ft. from the source will be 90 − 10 = 80 db.

A street of continuous traffic may contain so many sources of sound that they combine to form one line source. The reduction of noise from "line" sources is less rapid with distance than is the reduction from point sources. To what precise extent traffic conditions in towns may generally be likened to either extreme, will require further consideration and field measurement.

22. As part of the problem of urban noise, some mention should be made of the influence of reflection and the use of sound barriers.

23. The most common case of reflection as a noise problem occurs in city streets lined with high buildings. The multitude of rapid reflections from one side of the street to the other builds up a condition of reverberant sound; *i.e.* sounds appear to persist and overlap with one another, enhancing the general loudness and the sense of its continuity. No measurements appear to be available to show by how much the reverberation raises the loudness in the street, but it seems likely from theory that it will not exceed about 5 db. It will be useful to have this point examined.

24. A special note might be made of the effect of different facing materials used for the buildings lining the street. Again there are no measurements, but one

would expect that differences would only occur at higher frequencies, where smooth and shiny materials are less absorbent than brickwork and stone. The high frequencies are an important factor in noisiness, so that glass facings and polished stone would be expected to produce rather "noisier" streets than would other materials.

25. Special cases of reflected sound occur where buildings form "funnels" in plan, or where the direct path for sound is obstructed, and in such circumstances the reflected sound may acquire more importance.

26. When sound strikes a barrier it is reflected from it and an acoustic shadow is formed behind it, much in the same way as a shadow is formed by an obstruction to light. Sound barriers can then be used to shelter rooms which otherwise would be over-exposed to noise. Examples of such barriers are walls, buildings, hedging, trees, and so on. Generally speaking, these barriers are more effective for high frequencies than for low, because the acoustic shadows are sharper. There do not appear to be any measurements of the sound insulation value of such barriers, but in common experience they are found worth while. Even a row of trees and good hedging should give 5 db. reduction or more.

27. It is probably best to use trees and shrubs which keep their leaves all year round. Some examples have been suggested to the Committee. Of the conifers, there is yew, which forms good hedging though slow in growth, and macrocarpa, which is faster. Of the broad-leaved trees the most notable is the beech hedge, which retains its old leaves until new ones mature. There are certain other trees, such as the ilex, which retain their leaves, whether used as hedging or as the natural grown tree.

Trees which lose their leaves in winter will, of course, nevertheless be useful, for after all, windows are less frequently open in winter, and insulation requirements then are accordingly reduced.

28. The use of planting for quietness brings out a very desirable modern function of landscape architecture which does not previously seem to have received adequate recognition.

THE INSULATION VALUE OF WINDOWS

29. Having considered the loudness of outdoor noise, and the extent to which it may be reduced by the time it reaches a building, there remains for discussion the insulation value of walls and windows.

30. Windows and walls form a composite construction having two values of insulation, of which the lesser is usually the window. Composite structures of this kind have been examined theoretically,[1] and it has been found that where the area of the less insulating part is not less than about one-third the total, there will be no serious error in assuming that the overall insulation is that of the weaker component. Windows commonly form one-third or more of the area of external wall, and even for those cases where they are a little less, it would be wise to use the rule, and so assure a small factor of safety. In other words, only the insulation value of the window need normally be considered.

31. The insulation which can be assumed for a window depends indirectly on the method of ventilation. If no provision is made for cross-ventilation then it must be assumed that the window will often be opened widely and the sound insulation will be small. If proper provision is made for cross-ventilation, then the usual pressure differences between the air on opposite faces of a building will ensure that a flow of air takes place, even though windows are only open a little, and a higher standard of insulation can be assumed. If artificial ventilation is employed, then the full insulation value of windows can be expected.

[1] Davis, A. H., and Morreau, C. J., *The Reduction of Noise in Buildings*, Building Research Special Report No. 26, pub. H.M. Stationery Office. (*Out of print.*)

32. The widely opened window provides the least insulation, but how much it provides depends on the size of the open window area, and how much sound is absorbed inside the room. The reduction can be calculated, and the basis of calculation and some examples will be found in Appendix VI. Sound absorption itself is discussed later.

33. The examples may be summarized here. In a well-furnished office, even with a wide-open window, outdoor noises would be reduced about 5 db., and with the windows nearly closed to allow only a square foot or two of opening, this insulation rises to 15 or 18 db. An office which is sparsely furnished effects a reduction of only about 3 db. with the window wide open, but when it is nearly closed, the reduction is about 10 or 15 db. It thus would seem reasonable to assume that for design purposes any wide-open window could provide about 5 db. reduction, while if cross-ventilation is assured, a higher value, say 10 db., might be expected, because the windows need not be so widely opened.

34. If the sound comes at a definite angle as in the case of a room receiving street noises from below, then a further reduction in loudness in the room could be obtained by placing a special absorbent on the ceiling above the window where the sound will strike it directly. When the sound approaches a window very obliquely, less energy is able to enter the window, due to the smaller apparent size of the opening, but this only becomes useful when the angle between the sound and the window is less than about 20°.

35. When good sound insulation and natural ventilation is required in windows, some way has to be found of bringing in the air without the sound. The air flow through a building can be greatly enhanced if cross-ventilation is provided; there are usually sufficient differences in air pressure on the opposite sides of buildings to ensure air movement if there is a path. Then, with a positive action of this sort, it is possible to use smaller air intakes, and to introduce noise baffles which would otherwise reduce the air flow. The principle to be followed in the design of baffles is to arrange that the air-borne sound impinges upon absorbent surfaces, or travels along absorbent ducts during its passage into the room. One arrangement for double windows which is known to be fairly successful will serve as an illustration; the edges of the space between windows were lined with an absorbent, and the air was brought into the interspace at the top of the window and allowed to enter the room at the bottom. The actual vent openings in the glazing were fitted with louvres to deflect the sound. A double window of this kind should be about equal in efficiency to a closed window of single glazing, but it might be better to devise separate ventilators where convenient.

36. Cross-ventilation may reduce sound insulation between the rooms and the corridors, or between the rooms on one side of the corridor and those on the other, depending on which circuit is used. A duct across the corridor would seem a reasonable solution in many cases because it would be long enough to effect the necessary reduction. A duct should be split into separate passages, rectangular or triangular rather than square, lined with absorbent (Fig. 2). The splitters can be made removable for cleaning. The entry and exit to the duct should be protected against the direct entry of sound.

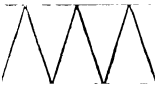


Fig. 2. VARYING CROSS SECTIONS FOR DUCTS

37. The reduction of sound along a duct depends mainly on the efficiency of the absorbent, the length of the duct, and its shape and size. The advantage of the elongated shapes mentioned in the previous paragraph is that there is a higher

ratio of wall area—and consequently of absorbent lining—to total cross-section, than with shapes more nearly square. In one case recently examined a duct about 7 ft. long, with a total open cross-section of 1·5 sq. ft. (subdivided several times), gave about 30 to 40 db. reduction between rooms across a corridor. Part of this reduction would, of course, have been obtained even if the openings had been left without the duct in them, but it shows, nevertheless, that reductions of a few db. per ft. are obtainable along such ducts.

In calculating the duct area required in any given case, some allowance must be made for the frictional losses in air flow due to the baffles and splitters.

38. If artificial ventilation is employed and windows are assumed closed, higher standards of insulation can be obtained as indicated in Table II. It will be seen that double glazing is very useful, though it should also be noted that to obtain insulation of the lower frequencies which are found in traffic noise, spacings of at least 4 in. are desirable. An absorbent lining on the reveals of the window, in the interspace, increases the insulation substantially; the absorbent should be efficient and applied in good thicknesses of, say, an inch or more.

TABLE II. INSULATION VALUE OF WINDOWS AGAINST AIR-BORNE NOISE

CONSTRUCTION	AVERAGE SOUND REDUCTION DECIBELS
21-oz. glass	
Double 21-oz. glass window at these spacings :	
½-in.	38
1-in.	42
2-in.	46
5-in.	49
8-in.	53
(improvements in insulation took place largely in the low and medium frequency range, important for traffic)	
¼-in plate glass	35
Double ¼-in plate glass 5¾ in. apart	58
,, ¼-in. ,, ,, interspace lined with absorbent	63 [1]

39. The points about the design of ducts apply also to ducts for artificial ventilation, and should be considered by heating and ventilating engineers.

40. It is worth noting that double glazing serves also to increase thermal insulation, which may be a factor where windows have to be large for daylighting.

STANDARDS OF QUIET

41. The levels to which intruding air-borne noise should be reduced are listed in Table III. They allow for the fact that there is always a certain level of background noise in a room, which helps to mask the intruding sounds. For instance, in a classroom, the breathing and various movements of thirty or forty children would combine to produce a background noise level as high, perhaps, as 50 phons. By experiment it has been found [2] that an intruding noise will not usually be audible if it is weaker by 20 phons or more than sound already present, so that noise entering the room would not have to be reduced to zero loudness to be inaudible, even if that were possible. In setting out Table III, the levels which have been suggested were not based on an attempt to make all intruding noises

[1] Approximate figure

[2] Fletcher, H., *Speech and Hearing*, pub. Macmillan, 1929.

completely inaudible, but, rather, to reduce them to a point where they will not normally be an annoyance. However, it might be noted here, as eleswhere, that these suggestions are based partly on theoretical grounds, and they should be confirmed with measurements. In particular cases allowance may have to be made for the personal factor, because some people are exceptionally sensitive to noise. Allowance should also be made for a district where the noise level is generally either very high or very low, as in the heart of a city, or deep in the country. As to the amount of the allowance, 5 or 10 db. is suggested, depending on whether or not conditions are thought to be extreme.

TABLE III. SUGGESTED STANDARDS OF QUIET

OCCUPANCY	LOUDNESS PHONS
Study or sleeping	15
Reading or writing	20
Boardroom	30
Sedentary office work ; quiet conversation	35
Average office, telephone work, and restaurant	40
Noisy office	60

OUTDOOR NOISE, INDIVIDUAL PROBLEMS

42. The Committee has examined a number of specific problems of outdoor noise which arise in practice, and the following are their observations.

ZONING AND SITING

43. The disposition of industries involving noisy operations, of sites for outdoor sports and of transport are problems for the town planner.

44. The first objective, so far as noisy industries are concerned, should be their segregation at a safe distance from residential and other areas requiring quiet. Powers exist under the Town Planning Act of 1932 whereby suitable control may be exercised by planning authorities. Noxious industries may be scheduled as "special industries," to be placed in special industrial zones. Although the example list of special industries quoted in the Model Clauses for purposes of example consists mainly of those which are smoke or smell producing, clauses relating to the erection and use of buildings make it clear that noise is considered a significant factor.

45. The location of such places as open stadia and arenas which might be a source of noise nuisance can be controlled under the same Act, through clauses affecting the use of land.

46. Transport, of all kinds, provides a general and serious source of outdoor noises.

47. Air transport, of course, is particularly deserving of attention. It is still in the course of development, and although it may be that most of the airports which will be required for future needs are now established, much can be done to avoid noise troubles around them after the war by controlling nearby development, and possibly by facilitating alterations in the use of land in the immediate neighbourhood of those which have not been too well placed in the past in respect of amenity. The siting of housing, hospitals, and schools in close proximity to airfields is particularly to be avoided.[1]

[1] Anti-Noise League Leaflet No. 11, *Noise and the Planning of Civil Airports.*

48. Airfields where aircraft and engines are manufactured and tested should be given special consideration. Testing may continue for long periods, and the noise travels some distance, being especially apparent on rising land round about. Recently there have been marked improvements in the insulation of aero-engine test sheds, and it seems likely that these may in future be made as quiet as may be considered reasonable.

49. Railways carrying heavy main-line traffic, and marshalling yards, are commonly a source of troublesome noise, though less widespread in its effects than that from airports or aircraft works. To some extent, the spread of the noise depends on the configuration of the land. If a railway is in a cutting, it is unlikely to be troublesome even near by, but if, on the other hand, it lies on low ground, with rising land all around, the extent of the noise nuisance is very markedly increased above normal.

50. Measures to deal with the problem can only be set out in general terms, for many other considerations have to be taken into account in the siting of railways and marshalling yards, and it is only possible for us to refer to factors which would operate towards a reduction of noise. (1) The noise should be treated at the source wherever this is possible. (2) Some limits of proximity for buildings should be set down, depending on the use to which the buildings are to be put, and the configuration of the land. (3) Development immediately alongside the railway should be considered with a view to its use in screening noise. As a general point it is suggested that planning authorities should examine the railway districts in the areas under their control and find out whether and to what extent their noise is proving a nuisance. In conjunction with advisers on noise reduction the special measures and policy of planning for each case could then be separately considered. In the occasional circumstances when new marshalling yards are proposed, the decision regarding their location should take into account, among the many factors involved, the question of noise.

51. Main roads present similar problems, though the noise levels are generally less. The method of treatment will be similar, consisting in the main of a limitation on the proximity of buildings for certain uses.

52. Recent suggestions from the Royal Institute of British Architects, and in the L.C.C. Reconstruction Plan for London, for running main roads along green belts where they enter cities, are much to be commended from the standpoint of noise abatement. They could with advantage be considered in connection with railways as well.

NOISE AND THE LAYOUT OF HOUSES AND FLATS

53. We have received valuable evidence from the Society of Women Housing Managers, about quietness in housing layouts. It was stated that, on the whole, older people and night workers appreciate quiet, while younger people do not mind a little noise. Complaints are general when flats or houses are put very close to a railway line, and the Society felt that close proximity to railways and main roads should be avoided, though a view of trains (presumably from a reasonable distance) was counted an attraction by many people because of its interest for children.

54. On the layout of the buildings themselves, the Society's main point was that courtyard plans are very noisy, due mostly to children playing. They suggested that more open plan types should be used.

55. Regarding the proximity of main roads and railways, definite limits are difficult to set, but it is felt that on more or less flat ground 150 to 200 ft. will be a suitable interval for general use, with larger distances from railway marshalling yards and other parts of the line where shunting is frequent and night work

customary. Less would be acceptable if the source of noise is screened by other buildings, or by being in a cutting, but on the other hand, if the housing is on rising ground, rather more distance will be necessary. A steep hill in a main road will also mean noisy traffic which can be very annoying at night.

56. Trees and shrubs can be used for screening noise, and for this purpose should be placed as near to the noise source as possible. Planting is also useful amongst houses and flats, to reduce the spread of noise; it should therefore be judiciously preserved, rather than destroyed, as is so often the case on new estates. Culs-de-sac form a useful aid to quiet planning, and a proportion of these should be used for night workers and others desiring quiet.

SCHOOLS

57. The sound insulation problem in schools, centres about the requirements of classrooms. There are four points to be noted: first, the choice of site; second, the location of the classrooms on the plan away from any noisy parts of the school, such as gymnasiums and workshops; third, adequate insulation between classrooms; and fourth, quiet floor coverings. The third and fourth aspects will be discussed in paragraphs 65 to 74.

58. Treatment of sound insulation in schools begins with the choice of site. In suburban districts it should not be difficult to choose sites which are quiet, the main points being to avoid proximity to noisy industries or heavy traffic. This serves both the requirements of safety and quiet. Where classrooms have to be located within, say, 100 ft. of a main road, planting should be used for screening, or other school buildings not requiring so much quiet should be interposed.

59. In urban districts, the problem is more serious, for the choice of site and its size are frequently restricted by cost and other factors. This will remain the case until it is possible to take a comprehensive view of the redevelopment of urban sites, and allot the use of land more in accord with the needs of the various types of urban building. Meanwhile, the selection of school sites for quiet remains urgent; we have in mind here particularly the development of trade and technical schools, though naturally we do not forget the usual elementary and secondary schools. The first point in the choice of a site for an urban school, as for the suburban school, is to avoid main roads, because classroom windows are often open and sound insulation very low. If the classroom block must unavoidably be placed near a main thoroughfare, attempts should be made by providing barriers to ensure some measure of insulation. Failing this, the design of the windows and ventilation system will have to be adjusted to provide adequate insulation.

60. The requirements of classrooms for quiet may be judged from data given in Table III. For study, reading, or writing, levels of from 15 to 20 phons are suggested for intruding noises, but these do not take into account the enhanced background noise due to the numbers of children usually in a classroom, and it may be assumed, therefore, that intruding noises for classrooms could be permitted up to 25 or 30 phons.

61. Table I, which gives the loudness of outdoor noise, can be used with the above figure to obtain an estimate of the insulation required. If the classrooms front directly upon a sub-arterial road where the loudnesses at the roadside may be 90 db., or at the face of the building 85 db., then it is evident that an average reduction factor of the order of 50 to 55 db. will be required. From Table II, where window efficiencies are listed, it becomes clear that such an insulation would require very good window treatment, with double glazing well separated; artificial ventilation, though unpopular, will also be necessary.

62. Classrooms facing local streets present a lesser problem. Noise levels outside might be of the order of 40 to 70 db., and insulation of 10 to 30 db. only would appear to be needed.

63. Earlier, in paragraph 17, reference was made to the annoyance caused in neighbouring homes by large numbers of school children playing together around the school. Every effort should be made to enclose playgrounds with adequate planting so that some reduction of noise can be effected.

64. The choice of a site is clearly an important factor in the design of a school in an urban district.

OFFICES AND OTHER BUILDINGS IN URBAN DISTRICTS

65. The principal source of noise in urban districts is from street traffic. It is useful, therefore, to consider the loudnesses which people in rooms facing the streets may experience. The usual type of building in British city development presents a continuous street façade of any height up to eight or nine floors or more. If the street carries heavy traffic, the noise level apparent at the roadside will probably be of the order of 90 db. (Table I). Occupants of rooms on the lower floors, who open their windows, may therefore expect to experience noise levels up to 75 or 80 db., at least. On the uppermost floors the noise level will probably be 5 or 10 db. lower, but this is about the most that can be hoped for unless the rooms are sheltered in some way, *e.g.* by set-backs. The whole of the rooms facing main thoroughfares may then expect intruding noise to reach 60 or 65 db. at the very least, when windows are open. From Table III it will be seen that this is suitable only for a limited number of occupancies. On city streets not frequented by buses and lorries the noise levels will be less, probably by as much as 20 db. (Table I). This represents a considerable relief, but not a condition which is beyond the desirability of improvement.

66. The designer may do one or all of three things:

i. He may employ elaborate window treatments and artificial ventilation.

ii. He may place the rooms where quiet is essential on a quiet part of the site.

or iii. He may set back the whole building from the street line.

67. The first alternative has obvious disadvantages in a climate where ventilation by open windows is acceptable at all times of the year. Nevertheless, it will give an undoubtedly useful standard of insulation. The windows should be double-leaved, of plate glass, and with a good thickness of efficient absorbent lining, the reveals—at least an inch—in the interspace. The glazing should be separated by 4 to 8 inches, because otherwise the insulation of low frequencies prominent in traffic, will not be very good, due to resonances.

68. The second course is to place boardrooms, managers' rooms, and other places requiring quiet, on the quietest parts of the site. In monumental or formal buildings this sometimes conflicts with the desire to give these rooms prominence, due to their function in the plan. The conflict must be recognized and resolved. In crowded city sites a quiet part of the site may be difficult to find, or it may face to the back where the outlook may not be very pleasant. A pent-house on the roof is a possibility not to be overlooked, and every opportunity to relieve the problem by such means should be taken.

69. The third alternative is to set the buildings back some distance from the street line; that is to say, the accommodation should be concentrated on the central parts of the site rather than around the edges, where it is next to the street noise. The latter course is customary to-day for a number of reasons. Intimate street architecture is attractive and street access is useful. Also height limitations tend to cause spreading as a means of obtaining accommodation. Fundamentally, however, it follows from the fact that plots of land are developed independently and at different times, as a result of which no other place for the buildings can

be found except on the street frontage, if they are to leave space for light and ventilation at the rear. The alternative course of putting the building on the centre rather than the perimeter of a block of land depends, then, on being able to view the redevelopment of urban areas as a whole, and on being able to go to reasonable heights.

70. At the same time, it should not be suggested that this course need invariably be followed. Not all types of occupancy need quiet. Street access is useful for both shops and garages, and they can be used to screen those where quiet is desirable. Again, where precincts are proposed, as in the new London plan where whole areas are devoted mainly to one activity such as education or government, then through traffic will be excluded and the streets should not be noisy enough to be troublesome.

71. These two points, though they show that quiet is an attribute, not of one, but of several types and combinations of development, nevertheless also serve to underline the importance of planning as an aid to quiet, and of viewing the use of urban land as a whole.

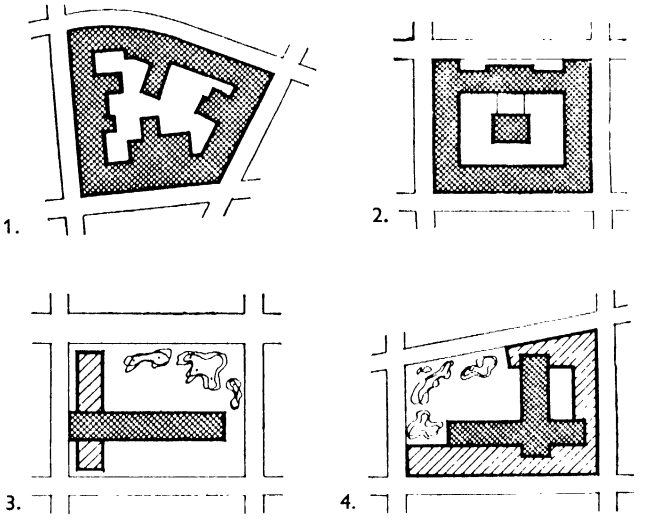


Fig. 3. LAYOUTS ILLUSTRATING NOISY AND QUIET PLANNING

72. Designers will recognize many of the possibilities at once. Some diagrams (Fig. 3) may help, however, to make clear the main points. The first two sketches show typical modern developments, one fortuitous and the other formal, both characteristically carried to the street line on all sides. The second two sketches show alternatives such as can be used where a block of land can be developed as a whole. The accommodation for which quiet is wanted is put on the centre of the site, away from the traffic, and further screened from noise by the lower buildings and planting lining the streets.

73. The noise reduction which can be obtained by such measures of planning will vary a good deal. Distance may account for 10 or 15, perhaps even 20 db., and the higher and the very low frequencies, both of which are annoying characteristics of traffic noise, should be especially weakened. Screening, both by trees and by buildings, will add usefully to the insulation. The reduction of street reverberation which must accompany this more open type of planning will be another significant advantage, which will be shared by people in the streets. By

these means it should not be impracticable to restore in urban areas an amenity of which sight has almost been lost in the hurried developments of the past century.

HOSPITALS

74. Hospitals in urban districts offer certain special problems of sound insulation upon which specific comment may be made. Table III suggests that in rooms for sleeping, intruding noise should be reduced to 15 phons. Allowing for a high background noise in urban districts, this figure might be raised to 20 phons. With this figure in mind, and considering what has been said of noise levels in streets, and taking into account, too, the desirability of natural ventilation in hospital wards, it seems clear that ample sites should be found for hospitals in order to give them the freedom to plan, and that they should take advantage of every possible aid to quiet design, the use of planting, the placing of noise barriers, and height. Scrupulous care should be taken to avoid placing wards so that they overlook any road which is or may be classed as sub-arterial or arterial. Where the choice of quiet sides of the site exists, surgical wards take precedence over medical wards.

A special point in the siting of hospitals is to avoid locating them over underground railways, especially those which come fairly near the surface. The vibrations may be a source of great trouble, and because they are of very low frequency they may be enhanced by structural resonance.

HOTELS

75. Hotels in urban districts also offer a considerable problem in sound insulation which may be aggravated by restricted sites. For instance, a hotel occupying a portion of the frontage in a block of continuous building is faced with two alternative outlooks for its rooms, one towards the street where the noise comes from, and the other to the rear, where the view may be poor. Frequently, too, hotels are located on main thoroughfares to attract clientèle, so that their noise problems for the rooms on that side are worsened; with 20 or 25 phons as the limit of loudness for intruding noise in bedrooms, and 85 or 90 phons as a likely level in the street, only the best of window treatments, associated with artificial ventilation, would seem to provide adequate insulation. Hotels on island sites are more favourably placed, but the site will often again be a prominent one, and any restrictions on the heights of buildings will tend to force a side-ways spread to the edges of the property, and a closer proximity to the street sources of noise. Height restrictions have a bad effect in this respect.

As a treatment for the problem it is only possible as a first step to draw attention once again to the need for some means by which the functional needs of a building may determine the choice of sites and their development, when the principles for quiet planning which are outlined in this Report can be given effect.

INDOOR NOISE GENERALLY

76. The study of sound insulation indoors follows the broad outline used for noise outdoors. There is first to be considered the loudness of the source, then the reduction possible by planning and structural means, and finally the degree of quiet which is required. In the following section these will be treated as before, first in general terms, and then applied to some specific problems. This part of the Report primarily concerns the architect and the builder, because the scope is limited to questions of design and structural techniques.

INDOOR NOISE GENERALLY

THE ORIGIN AND LOUDNESS OF INDOOR NOISE

77. There are two classes of indoor noise, one of which is termed air-borne sound, and the other impact or contact sound. Under the former heading are found such noises as conversation and the wireless, and under the latter are classed footsteps, furniture movements, and the noise of equipment such as pumps or lifts connected to the structure.

78. The loudnesses of some common air-borne sounds are shown in the following Table:

TABLE IV. AVERAGE LOUDNESSES OF SOME COMMON AIR-BORNE NOISES

	EQUIVALENT LOUDNESS PHONS
Loud wireless	80–90
Average wireless	65–80
Soft wireless	50–65
Conversation—normal	up to 65
Conversation—quiet	up to 45
Typing and tabulating—noisy office	up to 80

79. An equivalent Table for impact noises would be difficult to prepare. When the structure receives a blow, it is forced to vibrate, and its vibrations form the source of the noise. Thus footsteps on a bare floor would sound more or less equally noisy above it and below, but the actual loudness level will depend largely on the amount of energy imparted to the structure, which will vary a great deal.

REDUCTION OF NOISE AT THE SOURCE

80. Where noises can be reduced at the source this should be done. Equipment should be chosen with quietness in operation as an important criterion. Quiet motors and quiet gearing should receive particular attention, and guarantees covering noise in operation should be sought. Plumbing should be selected and installed so that it is reasonably silent. (See Appendix I.)

81. The reduction of impact noise at the source is one of the architect's problems. The most common impact noises in structures probably come either from the closing of doors, or from footsteps and furniture movements. The treatment of doors has not received the attention necessary to establish good standard practice in respect of quiet. Probably the best and simplest treatment would be by a continuous rubber or felt bead inset in the rebate, against which the door could come to rest. It would provide a more effective closure, thus cutting off the free air paths for sound, and prevent also the worst noise of slamming. To become established practice this treatment would require some sort of agreement for rebate design and for the beading as well, and the point should be given attention in the proper quarters.

82. The character of impact noises on floors depends largely on the nature of the surface and what strikes it. If both are hard, the noise will be rather high in pitch, but if one or the other or both are resilient, as for instance in the case of a

rubber heel striking linoleum, then the noise will lose its high-pitched character, and the sound generated will tend toward the natural frequency of the floor, which is low. Surface and sub-floor must, of course, be considered together; a resilient material would be less effective on boarding than on a more massive support such as concrete

PLANNING AND SOUND INSULATION IN BUILDINGS

83. Like outdoor noise, the treatment of indoor noise begins as a planning problem, the aim being to segregate the noisy and the quiet regions. This should be emphasized, for some problems which are aggravated by bad planning cannot be treated effectively and economically. As an example, a recently finished technical institute has a well-appointed lecture theatre which was intended to fill a need in the town as a whole. Unfortunately, the hall was placed beneath the gymnasium, and the result is frequently a great bother to the lecturer and his audience. An adequate treatment would be difficult to devise, though of course some relief can be obtained.

84. Vertical relationships of this kind between rooms require emphasis, because they tend to be forgotten in design, whereas the plans of the different floors in a building which always appear in the drawings bring out the horizontal relationships. A deliberate effort is probably required on the part of designers to alter this natural tendency to think of a building design as, in fact, a series of plans. The remedy might be to draw more section drawings.

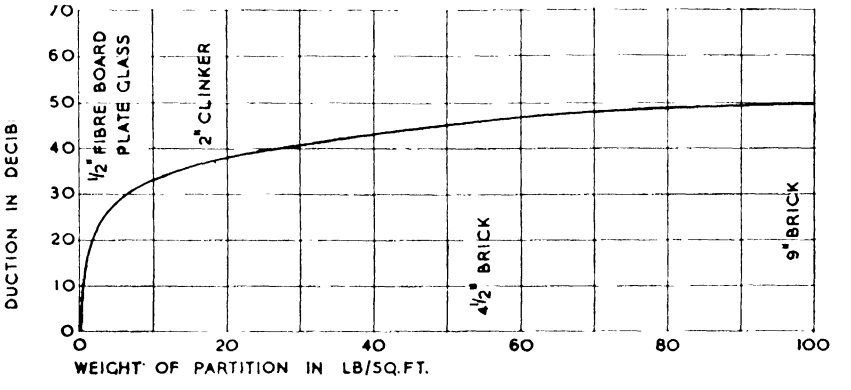


Fig. 4. GRAPH SHOWING TRANSMISSION OF SOUND RELATED TO WEIGHT OF STRUCTURES

THE TRANSMISSION OF SOUND IN STRUCTURES

85. Sound is transmitted in buildings in three principal ways:

i. By direct air paths, *e.g.* through cracks around doors and pipes, etc.

ii. By flexural movement of the walls and floors, which vibrate as a whole in the manner of plates or diaphragms. Low and medium frequencies dominate this mode of transmission.

iii. By vibrations set up inside the material of the structure itself, by which mainly high frequencies are transmitted.

86. In practice direct air paths are often overlooked though they allow a significant passage of sound. There are, however, no difficult structural problems involved, and appropriate details for treatments will be mentioned.

87. The flexural vibration of the walls, floors, and frame of a building is usually the most important means of transmission, especially for air-borne sound, because the low and middle frequencies which are transmitted this way are the most general cause of noise nuisance.

Transmission by flexural vibration in buildings might be described as follows:

88. Consider first the sound transmission from one side to the other of a partition or floor, either for air-borne sound such as wireless, or for impacts such as footsteps. The partition or floor is set in vibration by the incident energy, and the vibratory movement generates the sound which is then heard on both sides. Listeners on the farther side thereby get the effect of transmission.

89. The amount of vibration, and thus the amount of sound transmitted is dependent upon a number of factors, such as the mass, stiffness, elasticity, and density of the material of which the panel is made. So far as air-borne sound is concerned, however, the mass or weight alone is a reasonable guide to insulation, at least for solid, homogeneous constructions. The relation between weight and insulation is such that each time the weight per unit area is doubled, the insulation increases by roughly the same amount, approximately 5 db. This is shown in Fig. 4.

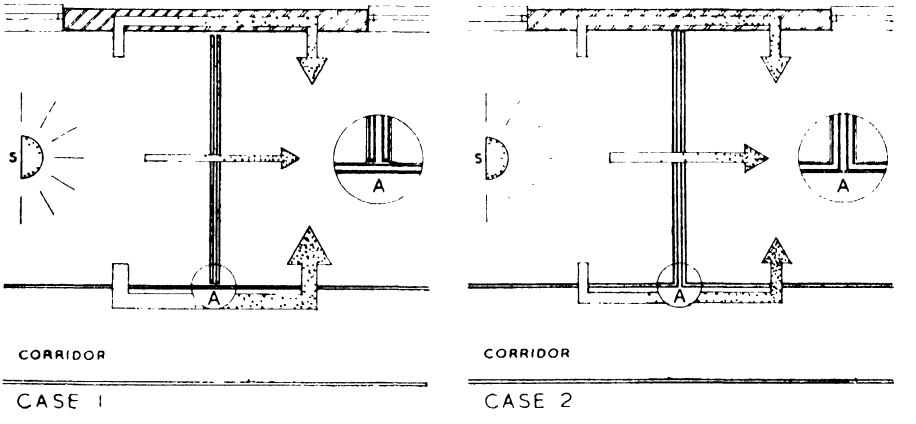


Fig. 5. DIAGRAMS SHOWING TRANSMISSION OF SOUND BY INDIRECT PATHS

90. The flexural vibrations will also extend themselves along the panels and the structure and thereby provide other, indirect, paths for sound between neighbouring rooms, and to distant parts of the building. These are often termed "flanking paths" for transmission, and their importance will be appreciated when it is realized that treatment of the intervening partition between two rooms can have only a limited effect while those other paths offer a lesser standard of insulation.[1] This is illustrated in Fig. 5. The arrows indicate roughly the proportion of sound transmitted by each path.

[1] Constable, J. E. R., "The Transmission of Sound in a Building by Indirect Paths," *Proceedings of the Physical Society*, Vol. 50, p. 368.

91. In Case 1, an efficient partition separates the two rooms, and the mass of the outer wall results in reasonable sound reduction by this path also. But the lighter wall on the corridor side gives a ready means of sound transmission, and the overall efficiency is therefore reduced. In Case 2, the corridor partition has been cut at the party wall (and the gap covered), so that the whole treatment is improved. This will show the way the flanking paths have to be watched, and in fact, in practice one would have to consider the floor and ceiling as well in these two cases.

92. The vibrations are transmitted along the structure until their energy is dissipated or until they come to a barrier of some kind. In this case a barrier could be formed either by a relatively weak or thin part of the structure, or a part which is comparatively stiff and heavy, such as a beam or chimney. Where it is weak and thin it would insulate because of its inability to transmit the bending moments which are induced by flexural vibration, while the heavy barrier would restrict vibration by its mass alone. These points can be illustrated by examples. If the two leaves of a cavity brick wall are linked by light wire ties, the transmission of sound between them will be much less than, for instance, if the ties are very stiff, or if brick ties are used, when transmission might be complete. On the other hand, if a wall is composed of two thin membranes, such as lath and plaster, fixed to a relatively stiff frame, then again the transmission of sound from one side to the other will be reduced, because of the heaviness and stiffness of the stud compared with the membranes. The degrees of insulation obtained this way will vary, but may be quite high. It is usual to refer to treatments of this kind as being of semi-discontinuous construction.

93. A still higher standard of insulation can be had by introducing a complete break in the continuity of the structure, either by leaving air gaps, or by inserting resilient materials in the proper places. This is called fully-discontinuous construction.

94. There are then three broad categories of construction so far as sound insulation is concerned. First there is the continuous construction, the maximum efficiency of which is limited in practice to the insulation which is given by weight per sq. ft. of the order of 9-in. brickwork. All conditions not requiring higher standards of insulation than this are within the scope of relatively simple structural measures. The second category—semi-discontinuous construction—restricts the transmission of sound either across or along a member, and weight for weight is generally much more effective than solid partitions. The fully-discontinuous constructions can offer insulation of a very high order. Experimental structures of a total weight about equal to 9-in. brickwork have been made to provide insulation equal to that which would appear in theory to require a solid wall of 10-ft. thickness or more.

95. Transmission which occurs by vibrations set up inside the material of the structure consists mainly of the higher frequencies. These vibrations can be generated in, and travel readily through, the denser structural materials such as steel, concrete, or brickwork, but not so readily in softer materials, such as timber.

96. With this type of transmission the most common cause of annoyance is impact noise, because impacts on, or vibrating machines in contact with, the structure can impart a great deal of energy to it. The movement of chairs on concrete floors and the slamming of doors are two examples which commonly illustrate this, and in a continuous structure these noises may be carried great distances. On the other hand, air-borne noise of high frequency is effectively reflected when it reaches the denser building materials, so that relatively little energy passes into the structure. This, in turn, suffers further reflection on

leaving the structure and entering the air once more, so that the overall insulation value of solid structure is usually very good for the high frequencies.

97. The semi-discontinuous and discontinuous treatments outlined for the reduction of transmission by flexural vibration will, in general, be effective for vibrations which are travelling in the material of the structure.

INSULATION VALUES

98. The average insulation of air-borne sound afforded by various types of construction is shown in Table V, below:

TABLE V. AVERAGE INSULATION OF AIR-BORNE SOUND BY TYPICAL STRUCTURES

STRUCTURE	WEIGHT PER SQ. FT.	AVERAGE INSULATION DECIBELS [1]
Homogeneous constructions	lb.	
½-in. fibreboard	0·75	25
Window glass	1	25
¼-in. plate glass	3·5	30
2-in. clinker block, plastered	18	35
4½-in. brick	55	45
9-in. brick	110	50
Semi-discontinuous structures		
Timber joist floor, plasterboard ceiling		35
Timber joist floor, lath and plaster ceiling		45
Timber joist floor, lath and plaster ceiling, plus pugging 20 lb. per sq. ft.		50
Timber stud partition, lath and plaster both sides		50
Timber joist floor, lath and plaster ceiling, plus floating floor boarding on battens on quilt		55
Fully-discontinuous construction		65 and upwards

99. It will be noted that ½-in. fibreboard offers a relatively small insulation. Comment on this material is desirable because it is so often called insulation board, and the term causes misunderstanding. It is an effective heat insulator but its porous structure and light weight does not contribute to sound insulation. Its contribution to this problem is, in fact, in terms of its sound absorption, for if sound absorbants are introduced into a room the general noise level can thereby be reduced a little.

100. The insulation values for impact sounds are not usually given in the same manner as those for air-borne sounds, *i.e.* as a given total number of phons or decibels, because when an impact occurs, the sound is generated by the structure itself, and the loudness of the sound will be dependent on the strength of blow, which may vary a great deal. Instead, the insulation values are given as a measure of improvement over some convenient standard structure untreated. For instance, a treatment of a concrete floor may be said to offer 10 phons improvement over the bare untreated concrete floor. On this basis Tables VI and VII have been compiled, giving insulation values for several floor treatments.

[1] Average to nearest 5 db., for a range of frequencies.

TABLE VI. AVERAGE INSULATION FOR IMPACT SOUND: CONCRETE FLOORS

	NOISE REDUCTION PHONS
Bare concrete	0
Carpets, etc.—	
⅛-in. lino, and ⅛-in. lino on roofing felt	5
Wood blocks, thin carpet, rubber	5–10
⅜-in. carpet on ⅛-in. underfelt, ¼-in. hard rubber-cork compo	10
1/16-in. sheet rubber on ¼-in. sponge rubber	20
Screeds, 2-in. thick, on following underlays—	
Clinker	5–10
Granulated cork, 1-in.	10–15
Slag-wool quilt, or eelgrass quilt	15–20
Glass silk quilt, single layer, or eelgrass quilt, double layer	20
Glass silk quilt, double layer	25
Boarding on battens on following underlays—	
Clips	5–10
Asbestos pads or felt pads, ½-in. thick	5–10
Fibreboard pads, ½-in. thick	10
Felt pads 1-in. thick, or rubber pads ½-in. thick	10–15
Eelgrass quilt, or slag-wool quilt, ½-in. thick	10–20
Glass silk quilt or rubber pads, 1-in. thick	15–20
Suspended ceilings—	
¼-in. plaster on ½-in. fibreboard on 2 in. × 2 in. battens in clips	5–10
⅜-in. plaster on ⅜-in. plasterboard on battens in felt-lined clips	10–15
No figures are available for metal lath ceiling suspended on metal supports, but their performance appears to be of the same order as the above.	

TABLE VII. AVERAGE INSULATION FOR IMPACT SOUND: TIMBER FLOORS

TREATMENT	NOISE REDUCTION PHONS
Normal board and joist floor, lath and plaster ceiling	0
Carpet on underfelt	10
Plaster on plasterboard ceiling	0
Pugging, sand, or ashes 10 lb. per sq. ft., or slag wool 2 lb. per sq. ft.	5
Sand or ashes 20 lb. per sq. ft.	10
Floor boards on cross battens on glass silk quilt, not nailed	5
Ditto on glass silk quilt, on sub-boarding	10
Ditto on fibreboard, on sub-boarding	5
Separate joists to carry ceiling	5

Further results for timber floors are given in Appendix II.

STANDARDS OF QUIET

101. Reference has already been made to standards of quiet, in connection with outdoor noise, and a Table was given there which applies equally to indoor noise. In addition, however, standards of quiet for impact sounds are required. They

are less firmly founded than those for air-borne noise, though there is a certain amount of experience available from which Table VIII has been compiled. It assumes that the noises being made will not be worse, for instance, than heavy footsteps. For noises of an exceptional character additional insulation would have to be provided, and for the noises of machinery, generated in contact with the structure, the advice of the manufacturer or a consultant should be obtained. On no account should the insulation of vibrating machinery be undertaken without competent advice; it is possible to produce a resilient support which at certain frequencies of the machine may become resonant, and thereby actually double or triple the amount of noise imparted to the structure.

TABLE VIII. SUGGESTED STANDARD OF INSULATION FOR IMPACT SOUND

OCCUPANCY	REDUCTION REQUIRED PHONS
Typing, noisy office	5
Telephoning, average office	10
Ministry of Health, Departmental Committee on the Construction of Flats for the Working Classes : recommended minimum for flats	15
Reading or writing, etc.	30
Study or sleeping	35

INDOOR NOISE, INDIVIDUAL PROBLEMS

102. The Committee has considered the application of the foregoing principles and data to the solution of sound insulation problems in the following types of building—houses, flats, schools, and offices. In addition some of the more important points about hospitals and hotels are noted.

DOMESTIC BUILDINGS GENERALLY

103. In our introductory remarks, we noted that sound insulation in the home had risen to prominence in recent years both because noise sources had become worse and because at the same time the transmission of sound has become easier. This continuing deterioration gives urgency to the problem, for conditions are already very bad. Hardly any of the low-cost flatted developments appear to offer an acceptable degree of sound insulation, and many of the terraced and semi-detached houses also give rise to complaint. It is clear, therefore, that steps should be taken to arrest these trends, and we have examined the problems with this end in view. We have found it possible to propose standards of insulation which we believe will prove to be acceptable as minima, and we have outlined means by which they may be reached in practice.

104. The following notes on noise in flats and houses are based largely on the evidence received from the Society of Women Housing Managers.

105. The most objectionable noises appear to be those of the radio, the movement of furniture, making the fire, coughing, mangling, plumbing, and children at play. Noises may be objectionable because they are widespread, or because of their nature, *e.g.* plumbing noise. No noise was included which the Society felt was a subject for educational treatment rather than structural improvement. It may be judged that such noises as that of "making up the fire" are disliked not so

[1] The reduction, in phons, is compared to a bare concrete floor assumed to afford zero reduction.

much because of their frequency or their nature as that they represent a psychological intrusion on privacy.

106. The sound of children at play was mentioned in particular as being associated with the courtyard type of plan, which was therefore disliked, and with balcony access. In fact, noise was said to be the chief criticism of the approach balcony, including, of course, the sound of footsteps of tradesmen and neighbours, all particularly annoying when bedrooms or sitting rooms are adjacent. Public access stairs are another cause of trouble when bedrooms are planned too near them, and it was stated that footsteps could be heard for five or six flights up or down.

107. It was the opinion of the witnesses that not much noise was transmitted between flats and houses *via* open windows. This is an interesting observation, inasmuch as it has frequently been mentioned in other quarters as a source of trouble. There is no doubt that it does occur sometimes, especially when the windows of flats face on to a nearby reflecting wall, a point which must be taken to favour open planning.

108. The radio was the subject of special comment. It was said that on the whole it was not operated at excessive loudnesses except by young people. A certain amount of radio noise transmitted is not a matter for concern in daytime, but tends to be troublesome at night because so many people go to bed about 9 o'clock in order to rise early.

109. A point was made about the use of quiet floor surfaces to prevent transmission to flats beneath. Carpets were said to be very limited in number in low-cost dwellings.

110. Accommodation for the night worker is regarded as an important part of the whole problem.

111. The Society confirmed the fact that insulation is worse in modern flats than in older ones, and also in modern houses as compared with earlier types.

112. Flats, on the whole, were regarded by the Society as sources of much more widespread noise complaint than houses, though, as evidenced by their remarks about the modern house as compared with older types, the latter is not above criticism. This bears out the Committee's impression that the house is often a borderline case, and is also confirmed by the experience of the Building Research Station. Serious troubles do occur, but they do not occur consistently.

STANDARDS OF SOUND INSULATION FOR DOMESTIC BUILDINGS

113. In discussing what minimum standards of insulation are required to give a reasonable freedom from complaint it is necessary to examine separately the problems of air-borne and impact sounds, and to consider each of these, first in terms of transmission between dwellings, and second, within the dwellings.

AIR-BORNE SOUND INSULATION BETWEEN ADJACENT DWELLINGS

114. In attempting to assess the actual values of air-borne sound insulation required between dwellings, we have been guided by a number of factors. In the first place, there is the known performance of certain common constructions. The concrete floor of about 4½-in. thickness, widely used for flats, yields about 45 db. reduction as a laboratory figure [1]; and is usually found inadequate. The 9-in. brick party wall gives a reduction of about 50 db. and is a less common

[1] The measurements given here are such as would be obtained in the laboratory, or in practice between normally furnished rooms. The reduction factors in practice for unfurnished rooms are below those of the laboratory.

source of complaint, though not sufficiently so to be acceptable as a minimum standard. Experience of a special construction offering about 60 db. showed that it avoided complaints which had been experienced with 9-in. solid party walls on the same estate, but it may perhaps be judged to be higher than is necessary for a minimum standard.

By this deduction it may be suggested that a figure of 55 db. would be suitable.

115. Consideration of the data given in the Tables in the Report confirm this. According to Table IV, the radio (presumably the loudest source of noise) may be expected to operate up to 75 db. or thereabouts, and according to Table III this should be reduced, in neighbouring bedrooms and living rooms, to 15 or 20 db. The reduction required by this calculation would then also be of the order of 55 db.

116. The Committee has, therefore, decided to recommend the figure of 55 db. as being the most suitable at the present time for a minimum standard.

117. Although we have described this part of the problem as being that of insulation between two adjacent dwellings, it is desirable to be more precise about the rooms to which it applies. The source of the loudest noises, such as those from the radio or the piano, is usually the living room or parlour, and in a neighbouring dwelling the rooms requiring quiet are these, and in addition the bedrooms. The full standard need be applied, therefore, only to the living rooms in adjoining dwellings and not between the whole of the dwellings as such. This assumes, as seems reasonable, that if each living room is treated, the insulation between a living room in one house and the bedrooms in the other will be sufficient. By avoiding a general insulation requirement of this standard between dwellings, the possibility is opened up of securing the necessary reductions by planning measures, such as by separating living and bedrooms in one dwelling from those in another by kitchens, stair-halls, garages, and so on.

AIR-BORNE SOUND INSULATION WITHIN DWELLINGS

118. It has been suggested to us that it would be desirable to provide in dwellings one room which is insulated to a higher standard than usual to-day, to deal with such problems as the night worker, sleeping by day, and children doing homework and practising music. This would undoubtedly often be desirable, and it seems to us that on the whole the best room to treat would usually be the living room, because it is the most likely source of disturbing noise. The importance of an insulated room for music practising was brought out in the questionnaire from the informal committee of musicians to which reference was made in the introductory paragraphs.

119. In attempting to decide what standard should be adopted between a living room and other rooms in a dwelling, reference can be made, as before, to experience with well-known constructions. The figures for $4\frac{1}{2}$ to 6-in concrete floors and 9-in. brick walls have been quoted, and to these may be added the $4\frac{1}{2}$-in. brick wall, which like the concrete floor has a reduction factor of about 45 db., the timber joist floor with 35 to 45 db. (depending on the ceiling used), the stud partition with 35 to 45 db. (depending on its facing), and the $2\frac{1}{2}$ or 3-in. breeze block, which when plastered affords about 35 to 40 db.

120. It seems to us too much to suggest that the standard should be as high as 50 db., the value for 9-in. brickwork, but on the other hand, it can be said that the 35 or 40 db. reduction of a breeze-block wall is not likely to be adequate, so that we are led to select the value which lies between these two, namely, 45 db.

121. It will be apparent later that some of the treatments suggested for insulation of living rooms in adjacent dwellings will at the same time meet the standard suggested for these rooms within their respective premises.

122. Between bedrooms and service rooms, and between the bedrooms themselves, it is desirable to maintain some standard of insulation, though obviously the requirements are not rigorous. It may be suggested that the plastered breeze-block partition offering a reduction factor of 35 db., represents an adequate standard to take.

123. We have not forgotten that these standards may occasionally be jeopardized by doors and other openings, such as for pipe runs. It seems likely, however, at least in respect of doors, that since most rooms open on to a common passage of some kind there will usually be at least two doors between any two of the rooms falling within the ambit of these standards. The insulation ought therefore to be adequate.

IMPACT SOUND INSULATION BETWEEN DWELLINGS

124. From the experience of members of the Committee, and from the evidence of the Society of Women Housing Managers, the most important of the impact or contact noises in flats and houses appear to be those of ordinary footsteps, children playing, furniture movements, mangling, and making up the fire. With the exception of the last, they are all problems of floor insulation.

125. Impact noise between dwellings was discussed in the *Final Report of the Departmental Committee of the Ministry of Health on the Construction of Flats for the Working Classes*, prepared in 1937. The Committee noted, in Appendix III of their report, that insulation gains of 10 to 15 phons over a bare concrete floor would be required as a minimum, and that 25 to 30 phons would be very acceptable. At the time, research had not yielded sufficiently inexpensive treatments to enable the Committee to make a firm recommendation. This position has now altered, and a recommended minimum standard of 15 phons improvement over a bare concrete floor could be implemented without difficulty or undue expense. We agree with the figure and therefore recommend its adoption as a standard. In respect of timber floors, which are basically noisier, the figure would be increased to 20 phons.

126. Again it is desirable to define more precisely to which rooms the standard need be applied. It seems clear to us that bedrooms and living rooms are those which most require the abatement of noise of this kind, so that the standard should be defined in terms of the floors in one dwelling which occur over the living rooms and bedrooms in another dwelling.

127. We have very little evidence that any serious impact noise on floors is transmitted horizontally in houses, though it sometimes is in flats. It is a problem which may come into more prominence in houses, if its treatment is overlooked, where frames or concrete floors are run continuously through adjacent dwellings. It is therefore a point which must be carefully watched in proposals for alternative types of construction to be used after the war.

128. The noise of footsteps on public access stairs and approach balconies is a serious problem, but not one for which standards of insulation can be suggested at the present time. Its treatment will be discussed later.

IMPACT SOUND INSULATION WITHIN DWELLINGS

129. There seems to be no evidence that this is a general problem of sufficiently serious nature to warrant setting a standard.

EQUIPMENT NOISE

130. The principal equipment noises in flats relate either to lifts or to plumbing. The treatment of lifts lies partly in planning and partly in the choice of types with quiet gates and motors, but it is impossible to suggest standards of quietness for operation yet. Plumbing noise is discussed in Appendix I.

HOUSES

PLANNING MEASURES

131. Wherever possible, it is best to approach sound insulation first as a planning problem, because it is likely to yield more generally beneficial results than local structural measures. The planning of the small house is, however, already circumscribed by many demands, and particularly those of economy, so that planning and structural measures will probably have to be balanced one against the other.

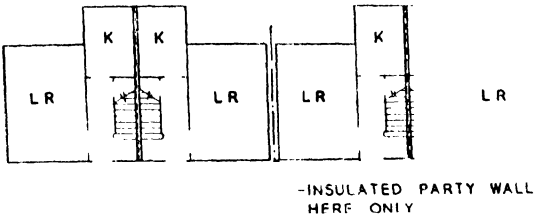


Fig. 6. PLANNING FOR QUIET IN TERRACE HOUSES

132. It is possible to locate the living rooms of semi-detached houses at opposite ends of the block rather than on the party wall, and various published plans do so. This provides the necessary insulation between these rooms, and also between them and neighbouring bedrooms, and reduces noise nuisance through open windows, a point which otherwise may become important when large bay windows are put next to one another.

133. In blocks of four or six houses this arrangement can also be used, but then living rooms may be adjacent on alternate party walls and structural insulation will have to be employed. This is shown in Fig. 6.

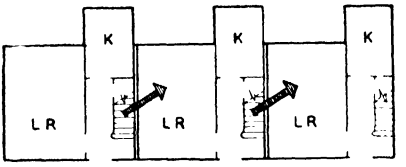


Fig. 7. NOISY ARRANGEMENT OF TERRACE HOUSES

134. A word of warning might be given about an alternative arrangement which may at first sight appear an attractive solution, *i.e.* to place all the plans the same way, so that every living room is separated from the next by a stair-hall (Fig. 7). This would mean that stairs are carried on the party wall next to a living room, and stair noises would probably be very noticeable, unless again a structural treatment is employed in each case.

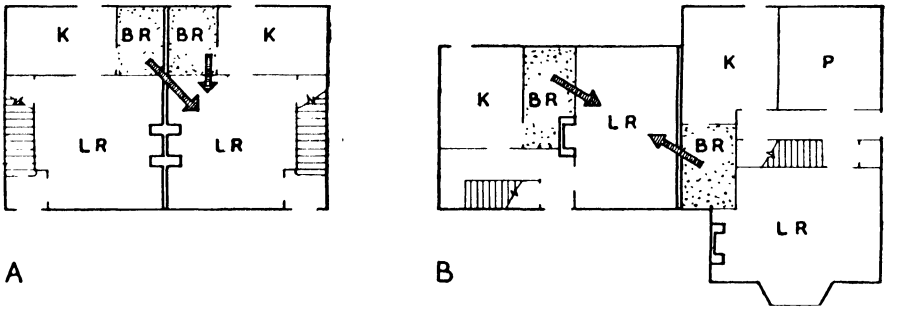
Another disadvantage of such arrangements is that bathrooms may come on the same party wall as living rooms, in order to get them over the kitchens to localize plumbing. The danger is that the noise of plumbing equipment will be heard in the next living room. A structural insulation for the party wall would deal with this, as also would the insulation of the equipment itself, as outlined in Appendix I. Bathrooms on party walls are not at all uncommon, and unless treated they form a most undesirable source of noise. Examples of plans of this type are given in

Fig. 8, taken from the evidence on planning and noise submitted to the Committee by Mr. D. D. Harrison of the Ministry of Works.[1]

135. If alternative plan types are considered for terrace houses, some arrangement of the "L" plan may be useful because it reduces the area of party wall, gives good separation of living rooms and screening of windows. The stepped plans are probably also useful in keeping down noise transmission *via* open windows, and the ordinary screen wall sometimes projected externally for privacy may help too.

STRUCTURAL TREATMENT OF INSULATION BETWEEN HOUSES

136. The guiding principle in developing treatments must be to reduce transmission both by the direct path, which is across the party wall, and by the indirect paths along the common flanking walls, floors, and ceilings. Three treatments will be described, each of which is based on traditional building practice. Alternative methods of construction will no doubt play an important part in reconstruction, but we do not know what they will be like and remarks regarding them, therefore, have to be limited to generalities.



A. Bathrooms next to living rooms on narrow site with a path for sound along the party wall to living room and adjoining bedroom over. A common type of plan.
B. Living rooms with adjacent bathrooms. This type of planning is often found where the end house in a row is placed at right angles to secure artistic effect. (Shaded areas indicate noise sources.)

Fig. 8. BAD LOCATIONS OF BATHROOMS FOR NOISE

137. *Method* 1. The method which in conception is probably simplest consists, in the main, of an inner shell in the form of a lining around the room. This is to prevent sound from reaching the carcass of the building. The best of the linings for this purpose is probably plaster on lath and battens. Other linings such as plasterboard, plywood, or fibreboard are less effective but acceptable. To develop maximum efficiency the battens should present a narrow edge for fixing, and in the case of strong and resonant materials such as plywood and plasterboard some soft or resilient material should be placed between them and the battens, or the battens themselves should be in felted or spring clips.

138. The lining need only be applied to those parts of the structure which otherwise offer a good path for sound transmission, *i.e.* to the solid, continuous parts of the building, such as brick walls and block partitions. Normally in a brick house this would mean all four walls of the living room, though possibly the wall farthest from the party wall could be omitted. Whether the ceiling would require a separate lining depends largely on its construction. If it is of concrete, which may be common after the war, it would require a lining treatment in the same way as the walls upon which it rests, owing to the continuous path otherwise open to sound. One or two other types of lining may be more useful here than the ones that have

[1] Harrison, D. D. "Planning against Noise," *Architects' Journal*, 26th Aug. 1943 and 2nd Sept. 1943.

been mentioned. Cork, for instance, or wood-wool slabs—both plastered—used as permanent shuttering for the concrete, are said to help insulation. A joist floor, on the other hand, is by its nature a semi-discontinuous construction, and it is doubtful whether any serious amount of sound reaching the ceiling membrane will be transmitted to the joists, or along them to the bearing walls. Thus the normal ceiling lining should be by itself suitable for the present purpose. At the same time, it must again be remarked that the best ceiling known for the purpose at present is plaster on lath—especially metal lath. Joists or concrete floors should, of course, be borne on the side walls and not on the party wall.

139. It seems unlikely that the living room floor in houses will require any special treatment. If it is of suspended timber construction, it should not be a source of trouble, and if it is a solid floor, resting directly on the ground, vibrations travelling along it will probably be sufficiently damped by contact with the earth. A suspended concrete floor, which would be an unusual construction for a house, might afford a path for sound transmission, and would require a lining in the form of a floating floor, to be described in Appendix III.

A diagram plan and details of this treatment are shown (Fig. 9).

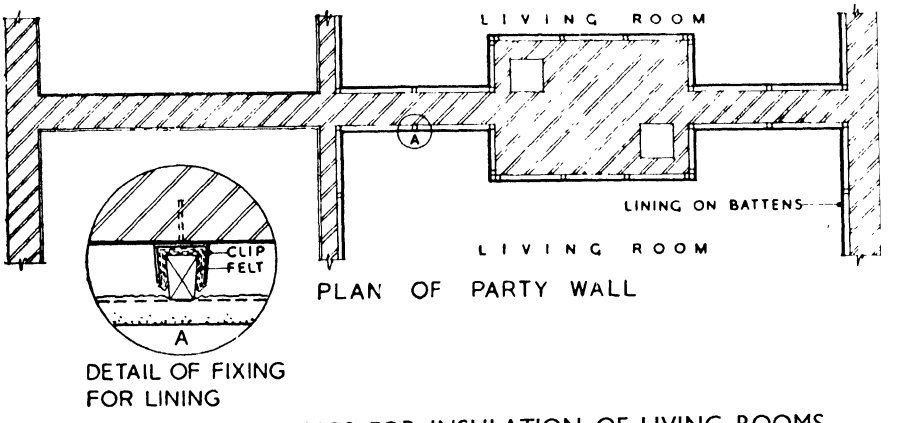


Fig. 9. USE OF LININGS FOR INSULATION OF LIVING ROOMS

140. One or two other points of detail should be noted about this treatment.

The fireplace opening offers an exposed surface over which it is impracticable to suggest a lining. It is, however, usually a heavy mass of brickwork affording only a restricted means of sound transmission, and we think it might be neglected. The chimney breast should be lined, the lining covering as much of the chimney front as possible.

141. Windows exposed in one room, and fixed in metal frames in contact with the solid carcass of the building, may offer a path for transmission to the neighbouring living room, but the likely degree of transmission is not known with accuracy. The window is in a sense a semi-discontinuous construction, but pending further investigation of the point, it would be wise to set metal frames in wood sub-frames. Windows having wood frames should not offer difficulty in this respect.

142. It may be remarked that the additional thermal insulation, and to some extent the lower thermal capacity surfaces provided by linings of the kind suggested, effects a fuel economy which should compensate for the added capital cost of the structure. It is understood that the Heating and Ventilation Committee will be reporting on this in some detail.

143. It should also be noted that the lining treatment would serve as sound insulation between the living room and the remainder of the house, and should meet the proposed standard of 45 db. without difficulty.

144. *Method 2.* The second treatment involves covering the direct path, *i.e.* the party wall, with linings, and cutting the indirect paths, so that transmission along them cannot take place. This can be done either with cavity or solid external walls. A straight joint could be made and some suitable inter-layer, such as a roofing felt, would be inserted to prevent the transmission of the vibrations to the party wall. (The inner leaf, linked to the outer by ties, would be stable for normal two-storey work.) Any partitions running into the party wall could be cut in a similar way so that no indirect paths for transmission remain, assuming, of course, that the floor is carried by these partitions and side walls, and not by the party wall. The floor and the party wall should be separated by felt (Fig. 10).

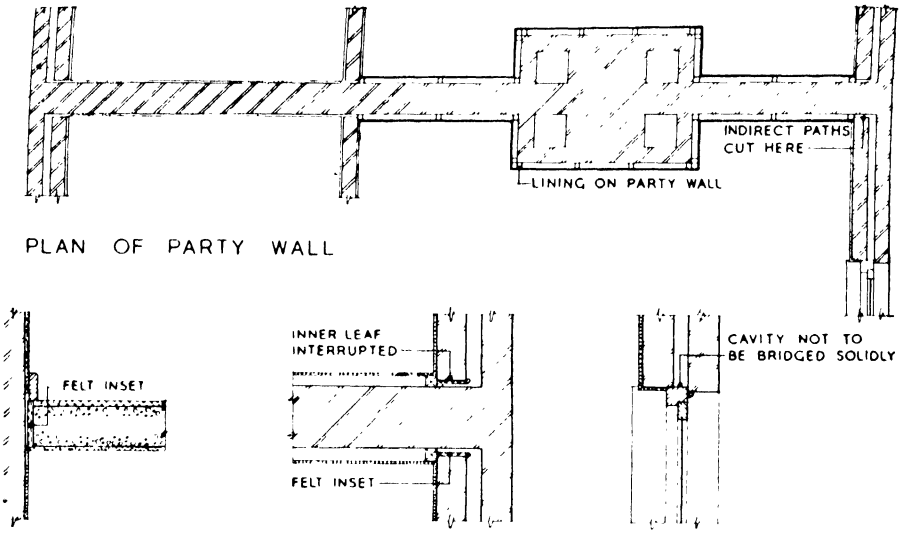


Fig. 10. SOUND INSULATION BY CUTTING THROUGH INDIRECT PATHS

145. It should be noted that where a flat concrete roof is used, the external wall comes in contact with a concrete roof common to the two dwellings and a path for transmission will be opened. It would be advisable to stop off the wall and any supporting partitions with a felt strip.

Another point requiring special mention is the treatment of the window opening where cavity walls are employed. The two leaves of the external cavity wall cannot be joined by a solid closure such as a tile creasing around a window or door, for any such treatment is known to bridge the insulation completely. Some alternatives appear to be suitable; one would be to use the standard pressed steel subframe for metal windows, and another, where timber frame windows are employed, is to use the frame itself to close the cavity. A damp course of roofing felt ought to be acceptable.

146. Unsuitable wall ties can bridge the insulation; information on this point is being obtained experimentally at present, but so far as is now apparent, no ties should be used which are heavier than the common "butterfly" type or Warrington tie in twisted wire. The twisted bar type is too heavy to be used in such circumstances.

The lining which is used across the face of the party wall would be the same as for Method 1, and the fireplace treatment would also be similar.

147. *Method* 3. In the third method, the party wall itself is divided so that so far as sound insulation is concerned the houses are separate shells. The party wall would become a cavity wall, its cavity continuous with the cavity in the external wall or, if the external wall is solid, the cavity in the party wall would be continuous to the outer face of the building, being closed there by a suitable type of expansion joint. The principal point to observe is that the chimneys should be divided in common with the other portions of the party wall; they can be joined again before they penetrate the roof, but this should occur only above a resilient sound-insulating layer inserted in place of one of the mortar joints. A suitable material has been found to be a form of asbestos cloth, as shown in the figure below. Alternatively the chimneys could penetrate the roof separately. The party wall should, if possible, be built without ties, or at most, with nothing heavier than the "butterfly" type of twisted wire tie mentioned before and preferably at generous spacings. When flat concrete roofs are employed, the junction with the supporting walls can be treated as for Method 2, or alternatively the roof can be interrupted at the party wall with an expansion joint, a useful feature in view of the risk of thermal expansion (Fig. 11).

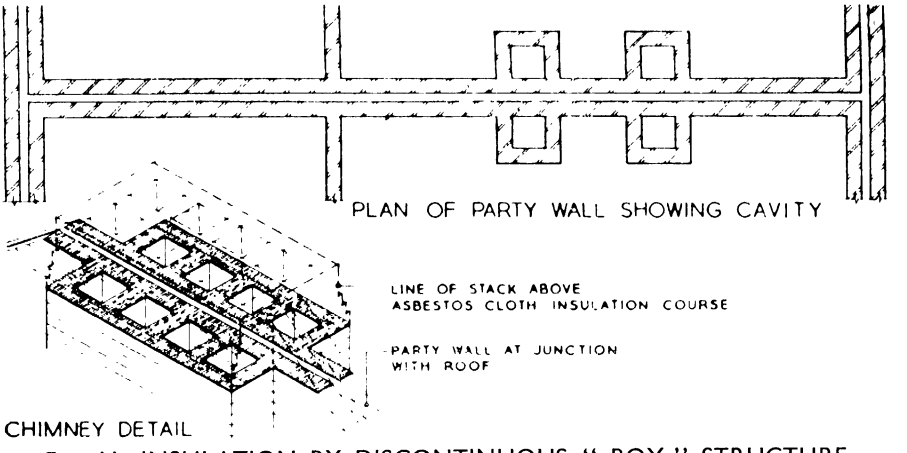


Fig. 11. INSULATION BY DISCONTINUOUS " BOX " STRUCTURE

148. Experience of this construction has been obtained and it is known to be economical and successful both for air-borne and impact sound. It may be commended as a reliable method to employ, yielding a reduction of about 60 db. for air-borne sound. In one case its cost was less than thirty shillings per house.

149. *By-laws.* It will be realized that in some districts the party wall is required to be 8 to 9 in. thick, of incombustible material in one thickness, thus excluding the possibility of cavity structure. In these cases it may be possible to secure a modification or a waiver of the by-laws. Alternatively, the party wall could be of 8-in. thickness in one leaf, and a lesser thickness in the other; the one leaf then meets the by-law and leaves the designer at liberty to employ a cavity.

ALTERNATIVE METHODS OF HOUSE CONSTRUCTION

150. Of the methods which may be employed after the war as alternatives to traditional construction for houses, only very general remarks can be made here.

151. It seems likely that framing in one form or another will be one of the basic alternatives.

Where the frame is rigid and continuous from house to house it is obvious that there will be serious risk of transmission between the dwellings. For example, concrete floors carried on a frame may transmit both impact and air-borne sound.

Some care has, therefore, to be exercised in developing this type of house to secure both economy and insulation. The best course ultimately may be to develop the continuity of the basic structure to the full, associating with it the idea of the "box-structure" as described by Fitzmaurice and Allen.[1]

Where the frame consists of frequent, relatively light members, faced on either side with a thin lining membrane, a different case arises, especially where such a construction is proposed for a party wall or floor. Their sound resistance is not likely to be adequate for this purpose, even with the best of linings, and with some it would be altogether inadequate. This would be particularly true with some of the prefabricated, non-continuous linings. On the other hand, these constructions have a certain amount of resistance to transmission along them, and are useful therefore as indirect paths for walls which otherwise would be indirect paths. Associated with robust party walls it is conceivable that the combination could be made into a good house from the present point of view.

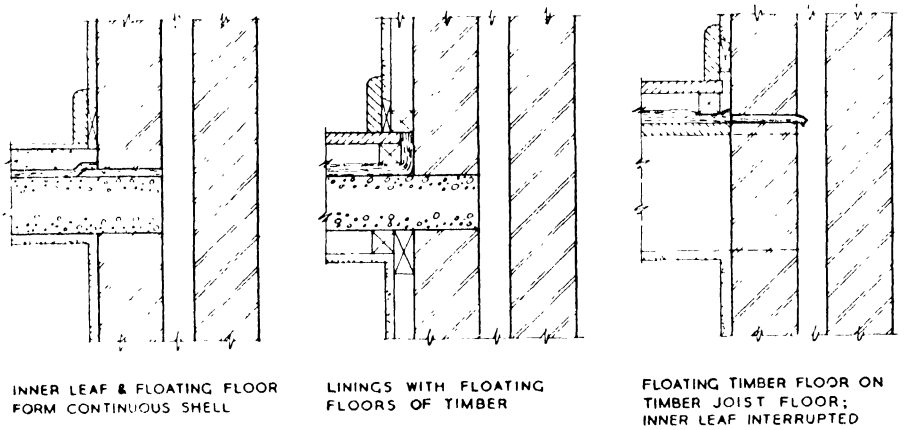


Fig. 12. INSULATION DETAILS FOR FLOORS IN FLATTED HOUSES

FLATTED HOUSES

152. In the flatted house it is usual to separate the flats horizontally by the normal party wall, and in this respect the sound insulation treatments required will be similar to those outlined above for houses. New problems are presented between the flats one above another, there being two ready paths for sound transmission, firstly and most important, through the party floor—usually a normal timber joist construction offering 35 to 45 db. insulation—and secondly, *via* any continuous partitions running up through the flats or *via* the inner leaf of an external cavity wall common to each dwelling.

153. So far as the floor is concerned, there are two alternatives : either to improve the joist construction, or to use a solid concrete floor. The timber floor could be brought up to the proposed standard by using a floating floor and a lath and plaster ceiling, and the concrete floor could be made adequate by a floating floor alone.

154. The treatments available for the walls and partitions are in principle similar to those described for houses. Linings could be used, or the vertical run of the walls which form the indirect path, could be interrupted and insulated at the party floor line. Three alternative treatments of the junction between party floor and external wall are illustrated in Fig. 12, to demonstrate typical details of the treatments.

[1] Fitzmaurice, R., and Allen, W., *Sound Transmission in Buildings*, pub. H.M. Stationery Office.

FLATS

155. Flats present the most urgent sound insulation problem before us at the present time. However, just before the war, research in this country had yielded treatments which were given successful full-scale trials. The design principles which emerged from the work have been described in detail by Fitzmaurice and Allen (*op. cit.*). The objective is to enclose all the rooms needing quiet conditions into a " box " or shell which is insulated from the supporting structure. This is termed shortly " box-structure," a " box " consisting of a floating floor carrying lining walls and a suspended ceiling. Fig. 13 (from Fitzmaurice and Allen's book)

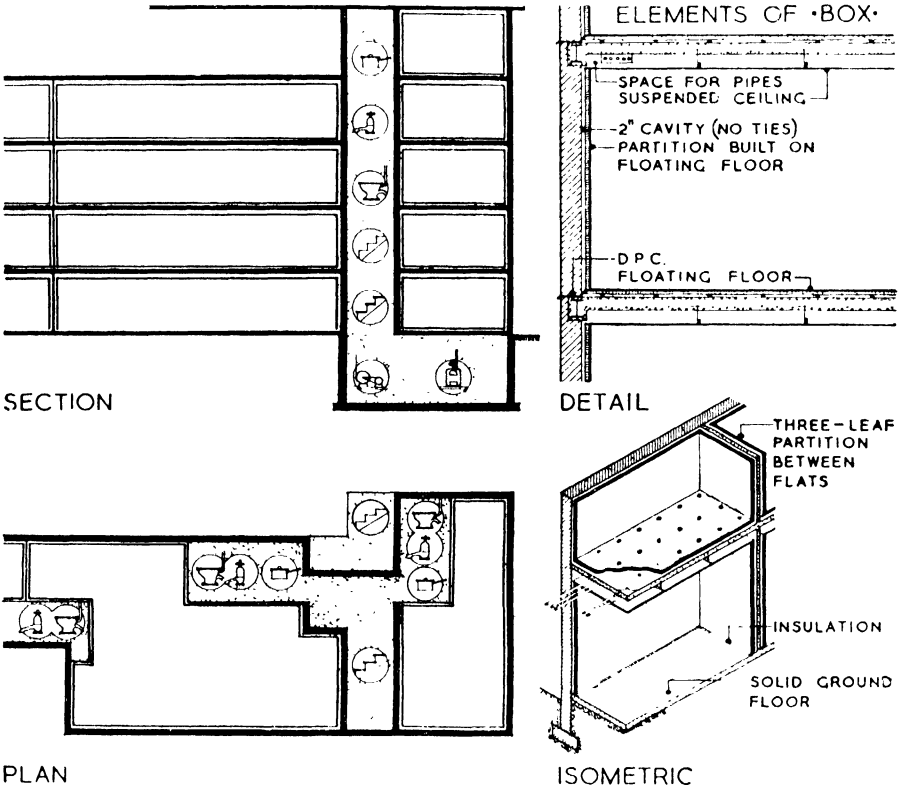


Fig. 13. DISCONTINUOUS CONSTRUCTION
DIAGRAMMATIC LAYOUT AND BASIC CONSTRUCTION
FOR EXAMPLE FLATS

gives a diagram plan and section showing the segregation of noisy and quiet areas, the noisy ones being shaded and consisting of the kitchens, bathrooms, and public areas. Typical details for a " box " are also shown.

156. The Committee realizes that this thorough treatment would at present probably be found to involve too great an additional cost for wide use. They therefore suggest a limited application to one room only—the living room—and perhaps one additional bedroom in certain cases, such as for night workers. The remainder of the bedrooms should be segregated from public stairs, and floors over bedrooms should be given floating treatments for impact insulation.

The Committee feels that these measures are the least which can be expected to provide reasonably quiet flats, and suggest that with familiarity with the details, the cost would be found within practical limits.

157. As illustrations of the Committee's suggestions, alternative treatments will be described.

158. The first objective is to enclose the living room in a box insulated from the supporting structure and consisting, as noted above, of treatments for the floor, walls, and ceiling.

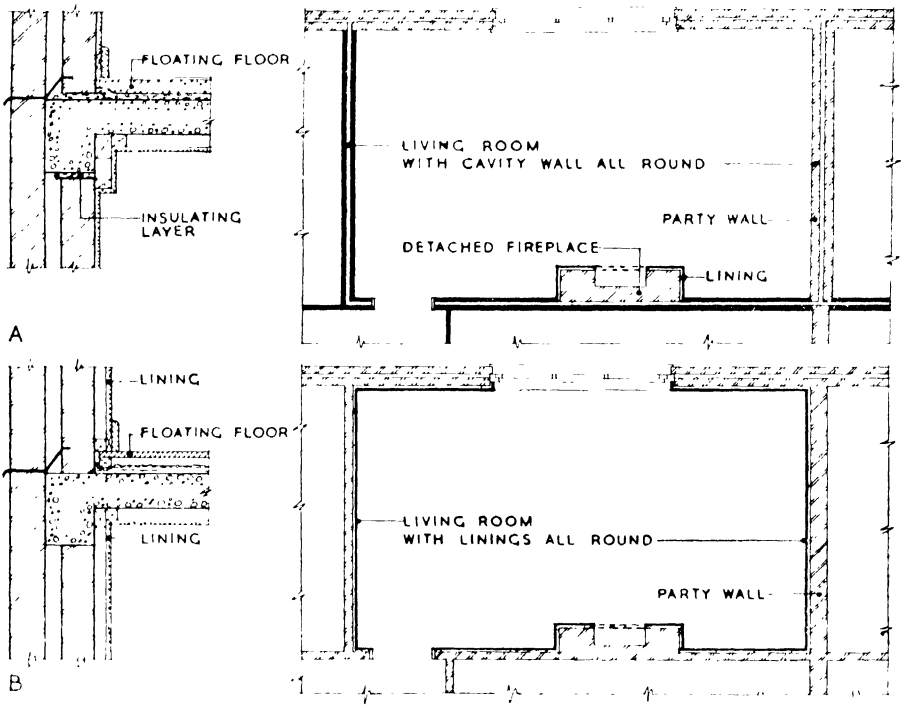


Fig. 14.

4. INSULATION OF FLATS BY DISCONTINUOUS "BOX" STRUCTURE
3. INSULATION OF FLATS BY LININGS IN THE LIVING ROOMS

FLOORS

159. Reference has been made to two simple types of floating floor, one of boards and battens, and the other a screed, on resilient quilts. They are described in detail in Appendix III. These should be perfectly satisfactory in flats, and can, if necessary, be sealed off to prevent bug harbourage. Floors of access balconies could be made less noisy by the use of waterproof latex coverings or some of the bitumen compounds.

WALLS

160. One simple course would be to use the cavity party wall and a cavity external wall together as two sides of an "independent-box," and complete it by carrying a cavity around the other two sides. The inner leaf should stand on a resilient mat all the way around, and finish at the ceiling in this or some similar way so as to interrupt the structural continuity. An illustration is given in Fig. 14A.

An alternative method would be to line the walls with a membrane such as has already been described for party walls of houses, *e.g.* plaster on lath on battens, or $\frac{1}{2}$-in. plasterboard plastered two coats, fixed in the same way. In the case of plasterboard, a strip of resilient material should be placed on the battens before the plasterboard is applied; alternatively the holding clips should be insulated. The battens should present a narrow edge for fixing.

This treatment is illustrated in Fig. 14B.

CEILINGS

161. These must carry out the "box-structure" principle. Experiments show that a ceiling suspended on hangers will give a useful measure of insulation. The hangers should be thin and as few as possible, and the ceiling battens or steel ribs can with advantage be wrapped in felt at the bearing points. The ribs, lath, and framework of the ceiling should be securely attached to the box walls at the top. An illustration of details from Fitzmaurice and Allen's book is given in the figure. Linings such as suggested for the walls are probably slightly less effective, but nevertheless possible for ceilings.

FIREPLACES

162. Here difficulties arise from the vertical continuity. Impact noises made by poking the fire, etc. cannot be insulated from flats above or below. Horizontally the difficulty can be avoided by dissociating the chimney stacks, as shown in the figure.

So far as air-borne noise is concerned, there is also some risk of transmission. The best course is probably to cover as much of the chimney breast as possible with a membrane lining as described for walls, leaving only the limited area around the fireplace opening exposed.

DOORS AND WINDOWS

163. The treatment of windows in cavity walls has been discussed in connection with houses. Doors in cavity construction present a similar problem, that of closing the cavity without bridging the insulation. The frame itself could be used as described for windows, or the cavity could be covered over with a lining of plaster on lath or plasterboard, etc.

EQUIPMENT

164. Plumbing is dealt with in detail in an appendix, where the main point is made that the most effective treatment is probably to insulate pipes and fixtures from the structure. Noise travelling along the pipes causes only a limited nuisance unless it gets into the structure. This is particularly true of the w.c. The pan should stand on some such material as cork or lino; the cistern should be held in insulated clips; and the pipes should be wrapped with heavy tape or asbestos twine wherever they go through, or are attached to, the structure. These measures should be cheap and effective.

Lifts, where these are used, should be located so that they are not adjacent to bedrooms or living rooms in flats. Quiet motors and quiet gates are essential.

Light switches remain a perennial source of trouble, and the more robust they are, the noisier they are. It may be possible to damp down some of the noise with suitable material around the box holding the switch; but we must express the hope that quiet switches will find their way into the market after the war, for this is the only reasonable and effective solution we can visualize.

SCHOOLS

165. In our earlier reference to the quiet siting of schools, it was noted also that the problem of sound insulation centred upon the location of the classrooms as well as their insulation.

166. Disturbance of a classroom by noise from elsewhere in the school frequently comes from the assembly hall, the kitchen, the gymnasium, music practice rooms, and certain rooms for manual training, such as wood and metal working. The sound may travel from these rooms to the classrooms *via* the open air, or along a structural path.

167. Considering the free air-paths for sound, it is clear that the classroom block and the noisier sections should be segregated. If possible, planting and other barriers should be employed to interfere with sound transmission between the two and they should face away from one another so far as reasonably possible. In urban school design, where sites may be so restricted that the plan cannot be spread, the segregation should nevertheless be followed within the buildings. Vertical relationships should be carefully watched where noisy and quiet areas are housed in one building, and in general machine shops and other similar rooms should be placed where the foundations of the machinery can be insulated. Administrative sections might be interposed between the two zones.

168. As a general rule, plans having open courts or wells, or even a quadrangle, offer risks of sound transmission between opposite classrooms. Here again planting may be used to good effect, and also as a means of separating classrooms from the playgrounds. The noisiness of quadrangles is increased by hard paving, and grass or some other alternative is to be preferred from this point of view.

169. Sound insulation between the individual classrooms, and between the classrooms and the corridors, is a problem principally for structural treatment.

170. Considering first the insulation of air-borne sound between classrooms, the requirements are not severe. Noises intruding into a classroom should not exceed 25 to 30 phons. It is doubtful if the noise generated in a classroom will often exceed 75 phons although, assuming the extending use of radio for school-work, especially in the teaching of music, noise up to this level may be anticipated. Even this would leave only the relatively modest requirement of 45 db. as a sound reduction factor for party walls or floors between rooms, which could be satisfied by an ordinary concrete floor, a 4½-in. brick wall plastered or a lath and plaster stud frame partition. It is doubtful whether partitions offering less insulation than this are frequently used in schools, but we propose, nevertheless, to suggest this figure as a standard.

171. There remains a risk of transmission *via* open windows, and it would be useful to screen between the rooms externally to reduce this path.

172. The amount of sound absorbent in a room affects the noise levels considerably. This factor will be dealt with elsewhere in the Report, but it may be noted that the figure of 45 db. insulation assumes rooms without excessive reverberation. Untreated rooms would require a higher standard of insulation.

173. Between two rooms, one above another, troublesome impact sound transmission occurs due to the movement of children's feet and school furniture. A minimum standard of impact insulation seems desirable, and we have in mind for this a figure of 15 phons improvement over a bare concrete floor, and 20 phons improvement over a timber floor.

174. Corridor noise is a frequent source of nuisance, both air-borne and impact. So far as air-borne noise is concerned it would seem desirable to extend the proposed standard for insulation between classrooms to deal with this factor. The value of sound absorbents in the corridor, as for the classrooms, will be dealt with later in the Report.

Impact noises should be dealt with, first, by the use of floor coverings as quiet as they can be, consistent with durability, and second, by the use of floating floors, except on the ground floor.

It is important to use good doors, well fitted, and if possible with a treatment to ensure closure of the air gap around the door. Otherwise insulation of corridor noise will be largely nullified.

OFFICE BUILDINGS

IMPACT SOUND

175. The modern office building is a highly continuous construction in which noises set up may be transmitted great distances. This applies particularly to high frequency sounds such as the closing of doors, lift gates, or walking over hard-surfaced floors, these being some of the noises commonly troublesome in office buildings. High frequency noises can be suppressed by the introduction of resilient surfaces where the impacts occur. To deal with the noise of closing doors, for instance, a resilient of some kind could be introduced in the rebate as suggested elsewhere. Doors and door frames have been manufactured which incorporate a single or double rebate, each of which carries a rubber or felt beading, replaceable when it is worn. The wider manufacture and use of doors of this kind would be a useful step towards the reduction of noise in modern buildings. Individual rubber or felt buffers are sometimes recommended for use in the rebates of doors to suppress the noise of slamming. They are effective, but care should be taken to see that they do not at the same time result in a too generous gap between door and rebate, with an increase of draughts and air-borne sound transmission.

176. The resilience desirable in floor coverings for office buildings can be judged by common experience. Wood block floors and thin linoleum are often found inadequate, though they are not as noisy as bare concrete or granolithic. Thin carpet on a thin underfelt, or a single substantial carpet, on the other hand, is found acceptable, as is cork or a thick cork lino. From Table VI it will be seen that these two groups offer respectively 5 phons and 10 phons reduction in impact sound, and it is evident, therefore, that the second figure of 10 phons represents a standard of improvement which might be considered the minimum desirable.

177. In interpreting this figure for practice, attention should be drawn to the fact that not only is it required to insulate the sound, but also to reduce the noisiness in the floor surface itself. It is not only the people in the storey beneath, but the occupants of the same floor, who are affected by impact noises in modern buildings. Therefore, a floating floor with a hard surface, although offering a higher standard of insulation, to the floor beneath, would not necessarily provide relief in respect of noisiness on the same floor. The use of a resilient wearing surface is, therefore, the essential factor in the solution of the problem. No measurements of noise reduction in this sense are available, but we feel there should be little difficulty in interpreting our intentions with satisfactory results.

178. In rooms which contain extensive accounting, punching, and tabulating equipment, it will be necessary to mount this so that vibrations are not transmitted to the structure, or the noise in the rooms beneath and near by may be serious. A good quality floating floor would provide an adequate solution of this part of the problem.

179. In urban buildings of all kinds there is another and serious risk of structure-borne sound arising from the nearby passage of underground trains. This problem has arisen acutely on occasions, and particular care should be taken on sites where it may occur. The problem appears to call for radical measures in the design of resilient foundations, which will normally require the services of a competent consultant.

AIR-BORNE SOUND

180. Air-borne sound transmission in offices is often partly masked by the background noise level in urban districts, but may be troublesome on occasions.

Probably the worst sources of air-borne noise are the rooms containing the tabulating and accounting equipment. In these it will usually be desirable to provide some absorbent to reduce the noisiness—a point which will be discussed in Part II—but even then the levels may reach 75 to 80 phons. If neighbouring rooms are used for quiet clerical work and other sedentary occupations, intruding noises should be reduced in these to about 35 to 40 phons (Table III). It follows that the insulation required for partitions between the two types of rooms would be of the order of 40 db.

This is not a value which is in any sense difficult to reach, and most normal partitions would satisfy it, but one point has to be watched, namely, the possibility of cracking. This may happen from a variety of causes, such as thermal expansion of the structure and shrinkage of the partition blocks. The result, so far as sound insulation is concerned, is a serious deterioration. We cannot discuss in this Report the treatment of so wide a problem, which is related to the skill and knowledge of the designer and the quality of building workmanship. It is evident, however, that it will be wise to use a partition which is likely to be free from cracking rather than one which may offer initially better sound insulation, but is more likely to have these other troubles.

181. Free air paths for sound transmission through partitions may also be provided when holes for pipes and conduits are made and not properly packed. Attention should be given to this point. Suitable packing is provided by sleeves of material such as asbestos cloth or rope.

HOSPITALS

182. Problems associated with sites for hospitals have been described.

183. In their internal arrangements the problem of quiet is, as for schools, firstly a question of segregation. For the patients, the wards are the main concern, and these should be adequately protected from the natural noisiness of both the main and ward kitchens, sluice rooms, lifts, and staff residences. Labour wards should be placed and treated with special care. The question is, first, one of insulation between zones, and second, within them. For instance, quiet, resilient floor surfaces are necessary in corridors and wards generally, such as were described for office buildings, and in addition quiet-closing doors and latches. Since main corridors are liable to be a source of noise, fanlights should be capable of keeping it out of the rooms, or should not be used. In the residences, internal insulation is more important, because one shift of nurses must be on duty at night and sleep by day. The insulation required will depend on the plan and functioning of the residence, but obviously it should allow the necessary noise of recreation to be made without disturbing those who are asleep.

184. Hospitals which occur over underground railways should be carefully considered as a foundation problem. The low frequencies excited by the railway give rise to resonances in the building structure which can be the cause of acute discomfort. A truly resilient treatment of the foundations is called for if such sites as these cannot be avoided.

HOTELS AND HOSTELS

185. The site problems of hotels have been discussed earlier.

The normal hotel room will vary as a noise source depending on the type of clientèle. Where the rooms are used for residence, and may contain radios, it would seem correct to consider the rooms to be the equivalent, or nearly so, of living rooms in separate dwellings, and provide a reduction factor of, say, 50 db. between rooms though 45 db. has sometimes been found acceptable. This would

apply also to residential hostels. For hostels for students, especially students of music, higher figures could be suggested; for practising music at least 55 db. should be the aim in sound insulation. Insulation values of this level or more are quite practicable to-day, by means which have been described. Ordinary hotel rooms where radio is not used are not likely to be a source of noise exceeding, say, 65 or 70 db., and assuming that intruding noise in an adjacent room should be reduced to 15 to 20 db., it will be seen that an insulation value of 45 db. (the equivalent of 4½-in. brick or concrete, a good stud partition, or a double partition) should be adequate. Hotel rooms are usually sufficiently well furnished to be considered fairly absorbent, which will help to reduce noisiness.

186. Impact sounds are unlikely to be troublesome in hotels, where carpets are usual, but may be a nuisance in hostels. Plumbing and other equipment is a frequent source of annoyance. Rooms should not be placed next to lift wells and public stairs, or to pantries and lobbies. As for the plumbing itself, the general measures of treatment described in Appendix I are applicable and important.

187. As an instance of the type of planning-point to watch, the location of ballrooms may be noted; these have sometimes been placed at the foot of an open well, with a glazed roof, and the noise of orchestras playing, late at night, then disturbs the whole of the rooms on the otherwise very quiet court. This also applies to kitchens and other service rooms if located in such positions.

FACTORIES

188. The factory occasionally has insulation requirements inside, which are somewhat special and hardly subject to generalization, though they should follow the principles laid down here. Where, however, the factory contains machinery, the noise of which escapes to cause a nuisance in neighbouring districts, an exceptional noise problem arises. In this sense the factory may become a noise nuisance, against which an injunction may be obtained under by-laws. The noise probably escapes principally through the roof, which is not commonly more than thin sheet material, and through the walls if these are also of this construction. Open doors, windows, roof lights, and ventilators may, of course, add other means of escape. In such instances it would be desirable to suggest insulation to restrict the noise to the premises themselves, or preferably to take advantage of the powers given in the Town Planning Act to limit a noisy industry to a special industrial zone.

189. Another aspect of factory sound insulation might be noted. A number of cities are faced with the problem of the space occupied in central districts by large numbers of small "one-man" industries. One aid to a solution of the problem might be to accommodate them in larger buildings where they could rent space and communal services. A disadvantage of that type of building might well have been the inordinate sound transmission which would have taken place, but this transmission could now be averted without difficulty.

CONCLUSION

190. From the foregoing discussion it will be clear that sound insulation is primarily a problem for the architect and town planner, and that effective treatment is only possible in design. Nothing that can be added readily to a building after it is erected can have more than a limited effect on the insulation. This means that certain aspects of sound insulation should be classed with the other desiderata of which account has to be taken in first formulating a design.

PART II. THE ACOUSTICS OF AUDITORIA

191. The problem in acoustic design is to ensure the clear understanding of speech sounds, to bring out the beauty of musical tone, and to promote the reduction of noise in rooms. Where speech or music is the problem, the aims should be to get the sound from the source to the listener clearly and strongly and to have a good balance of tone between the high, middle, and low frequencies. These are quantitative and qualitative aims, to be achieved through a proper shape for the room, so that the best use is made of direct and reflected sound, and through the use of sound absorbents by which the persistence of sound and the balance of tone is largely controlled.

192. This part of our Report is divided into three sections, the first two being devoted respectively to the shape of the room and the use of sound absorbents; while in the third part some specific problems are examined.

SHAPE AS A FACTOR IN ACOUSTIC DESIGN

193. What part does shape play in acoustic design? This question will be examined in terms, firstly, of the direct path for sound between source and listener, and secondly, of the functions and control of reflected sound.

DIRECT SOUND

194. It is elementary that there should be an adequate direct path for sound. In a room a listener hears a sound first by the direct path, and subsequently by a series of reflections which usually are not separately distinguishable, and die away more or less slowly as "reverberant" sound. Some reverberation is always desirable in a room, and in any case could hardly be avoided. But it is essential to the clarity of the sound that the first hearing of it shall be loud enough to dominate the reverberation; and this means that the direct path will have to be good.

195. In general, an adequate direct path will be assured when the source of sound is freely visible to the listeners. This is not always a guide, for sound is usually projected slightly upward from a source, and listeners seated near by, but at a lower level, may see the source better than they will hear it. This is not uncommon in halls where the source of sound is on a raised platform. If the sound is weak to the nearer members of the audience, these then have a further disadvantage that it leaves them more susceptible to the confusing effects of reflected sound, and it will be seen later that, in fact, reflected sound is a fruitful cause of trouble in these forward seats in some types of hall. This gives rise to questions of platform design which will be discussed later. It also emphasizes the importance of well-ramped seating.

196. Another factor in loudness is the length of the direct path from source to audience. It must always be considered desirable to bring listeners as near the source as is convenient without locating them too far to either side of it. A comparison of different types of plan, such as Bagenal has made,[1] brings out the fact that, in general, the modern fan-shaped hall is best in this respect. It accommodates the audience within good limits of horizontal angle, and because of the spread of the plan at the rear, the maximum distance from source to farthest listener is much less than with other types of hall, in particular, the simple rectangle. In addition, it means that a good percentage of the audience can be put in a balcony which need only be shallow, and which, therefore, throws the people beneath it into a much less troublesome acoustic shadow. In Fig. 15 a fan-type plan is compared with a simple rectangular shape of equal area, both on ground floor and balcony. The shaded area indicates the region of deep acoustic shadow.

[1] Bagenal, H., *Practical Acoustics and Planning Against Noise*, pub. Methuen, 1941.

197. There are occasional exceptions to this rule about the importance of direct sound; many people will have observed, for instance, that a cathedral choir, hidden from view in some distant part of the building, nevertheless can produce music for which one could desire no better listening conditions. These are special cases, however, and rarely rise as a factor in modern design, where rapid, clear performance and good articulation are the usual requirements.

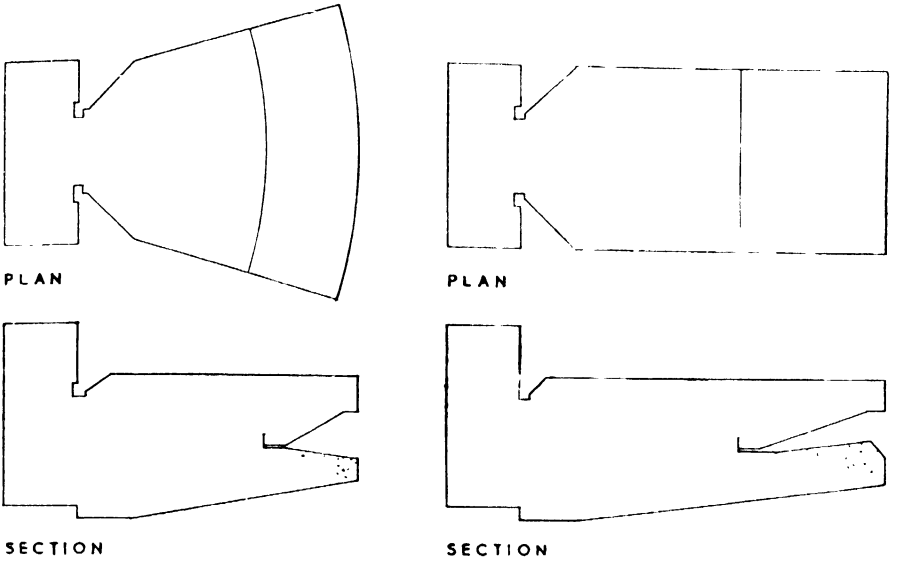


Fig. 15. COMPARISON OF PLAN TYPES OF EQUAL AREA

REFLECTED SOUND

198. Turning to reflected sound, a problem is encountered which has more aspects, and requires more subtlety in design than the other. Despite the importance attached to direct sound, emphasis must be laid also on reflected sound, for failure to understand the working of the principles involved has been the most frequent cause of serious acoustic failure.

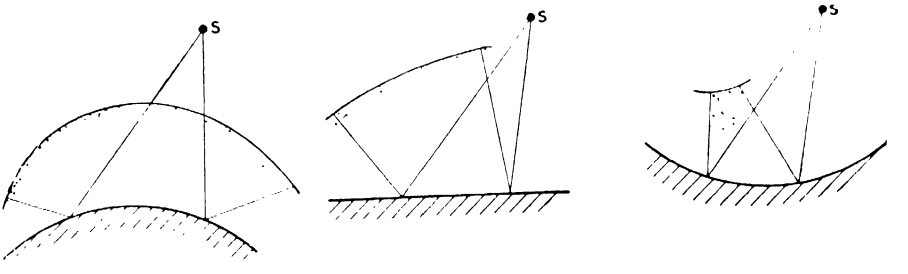


Fig. 16. REFLECTION OF SOUND BY VARIOUS SHAPES OF SURFACE

199. The laws of sound reflection resemble those of optical reflection, the most important of which, for the present purpose, is that the angle of reflection is equal to the angle of incidence. A concave surface will concentrate the reflected sound—just as does a concave mirror with light—a convex surface will disperse it, and a flat one will reflect it undistorted, as shown in Fig. 16. The shading of the wave front is an indication of the relative concentration of sound in it.

In comparing light and sound in this way one has to remember that sound waves are much longer than light waves, being measured in feet where the others are measured in millionths of an inch, so that the reflecting surfaces need to be very much larger to note comparable effects.

200. Another point of paramount importance in reflection is the velocity of sound. A listener in a room hears a sound first *via* the direct path, and then as a series of reflections. These usually follow one another so rapidly that they are heard simply as reverberation which dies away as the energy is dissipated. If the decay of reverberation is uniform and at the proper rate, then it will not confuse any successive sounds, and only adds a sensation of resonance, which to some degree is desirable. On the other hand, if the decay takes place in a series of steps, or as independent, relatively powerful reflections, then there will be confusion, the extreme of which is found when pronounced echoes occur. Some interesting curves illustrating the decay of sound in theatres were published recently by Mason and Moir.[1] They generated a single sound pulse on the stage in a hall and recorded at various seats the time of receipt and magnitude of the direct sound and the various reflections in the reverberation. Two of their curves, one of relatively good conditions, and the other rather bad, have been reproduced in Fig. 17.

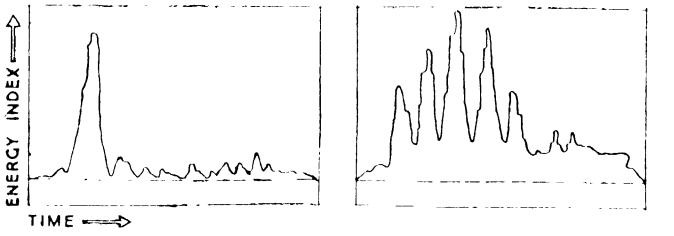


Fig. 17. CURVES ILLUSTRATING THE DECAY OF SOUND IN A CINEMA

In the first, the dominance of the direct sound is clear, while in the second, the reflections are not only strong, but in fact, stronger than the direct sound. The illustrations are reproduced by permission of the authors and of The Institution of Electrical Engineers.

201. Further work, reported in the same paper, indicated that a prominent reflection could usually be tolerated if it followed the initial sound with a time delay of not more than $\frac{1}{20}$th sec., but that beyond this difference there is a deterioration in intelligibility. This work was concerned primarily with conditions in cinemas, where speech is the main factor, and the limit of $\frac{1}{20}$th sec. can probably be taken as appropriate to all auditoria for speech. A comparable figure of $\frac{1}{15}$th sec. has often been mentioned in connection with auditoria for music. Sound travels at a speed of about 1100 ft. per sec. in air, and, therefore, in $\frac{1}{15}$th and $\frac{1}{20}$th sec. respectively, it will cover distances of 75 and 55 ft. From this it can be deduced that prominent reflectors should not be located so that reflections from them to the audience have to travel a path more than, say, 60 to 75 ft. longer than the direct path. Domed and vaulted ceilings 30 or 40 ft. high, and curved side or back walls in big auditoria are common sources of echo, and the reasons are found to lie both in the concentration of sound, and in the distance it has to travel. The *locus classicus*, as Bagenal remarks (*loc. cit.*), is the Albert Hall, where "concentrations of sound from domed ceiling arrive in arena seats at an excess path of some 200 ft., or after the lapse of one-fifth of a second, causing rapid music to be heard a beat late." Conversely, the convex surface can disperse and weaken a reflection, as

[1] Mason, C. A., and Moir, J., "The Acoustics of Cinema Auditoria," *Journal of The Institution of Electrical Engineers*, Vol. 88, Part III, No. 3.

will a surface which is highly absorbent. Even a flat surface of large size can be a source of trouble if wrongly placed in an auditorium.

202. The length of path for reflected sound, and the shape of the reflector are of the greatest importance in acoustic design, but in a sense they are negative because they emphasize what to avoid, rather than what should be done. Observance of them will ensure designs which are not significant failures, but not necessarily designs which make the best use of reflected sound. It is desirable, therefore, to discuss the positive functions of reflected sound, which are:

a. Reinforcement of the source.

b. The dispersal of sound for uniform decay at the proper rate.

c. Reinforcement of sound in distant seats.

203. Considering the first point, some sources of sound, such as the human voice, and individual musical instruments, or small groups of them, are often insufficiently strong for larger halls and require to be reinforced. The source should then be located where nearby walls and ceiling surrounding it can be employed as reflectors, these being adjusted in shape to reflect the sound towards the audience generally.

204. Emphasis is placed on the use of surfaces near the source, because of the necessity for a powerful reflection to follow the initial sound with little delay when it is intended for reinforcement. It would be undesirable, on a stage, for instance, to have reflection from a cyclorama 25 or 30 ft. behind the source, since there would be an excess path of 50 or 60 ft. and, in consequence, an echo.

205. Larger groups of instruments have more strength and need correspondingly less reinforcement. On the other hand, it is an advantage to the players themselves and to the conductor if some nearby surfaces can be employed for inter-reflection so that they may hear themselves and one another better. It helps them in playing and in keeping together. Probably the best surfaces to use for this purpose are those overhead, and walls with an inward tilt. Reinforcing sound in this way makes a great difference to the apparent effort required of the performer. To perform in a highly absorbent room, or where one receives no assistance from nearby surfaces, is like performing out-of-doors. A full stage, of the theatrical type used for music, always offers this problem in some degree which, in one case at least, is said to have been solved by "feeding" the soloist's voice back to him electrically, from the side of the stage, after a slight time lag, thus creating an artificial sensation of reverberation.

206. The second function of reflected sound concerns the development and decay of reverberation. Reverberant sound is always desirable for the performance of music—especially choral music—and even for speech, though for the latter the reverberation should be quite short if syllables are to be heard clearly. In some special cases, such as cinemas, where some reverberation is usually found in the reproduced sound, as little as possible further reverberation in the theatre itself may become the aim.

207. When it is desired to develop reverberation, it is necessary to disperse the reflections, so that too much sound will not find its way quickly to any powerful absorbent such as the audience. Absorption can take most of the energy out of the reverberation and cause it to drop suddenly, with an added risk of a subsequent separate reflection being heard as an echo. Dispersal is best effected by using broken or decorated surfaces, in asymmetrically and convex shapes and stepped planes. Large unbroken flat areas are best avoided, on the whole, because the reverberation then tends to decay in a few big steps rather than in many little ones, though the effect of dispersal can be obtained in some degree from flat surfaces by laying out on them a pattern of distributed sound absorbent.

208. When it is desired to reduce the reverberation, some dispersal is still desirable to get a smooth decay curve, but more absorbents would be introduced to take the energy out of the sound as it impinges on the various surfaces. Also, it will be correct in this instance to direct the sound deliberately to the audience, which will absorb a good deal of it. This aim can be seen in many modern auditorium designs, of which that illustrated in Fig. 18 is a good example.

209. It has been put forward by Mason and Moir (*loc. cit.*) as a good pattern for a cinema theatre. Their aim is to provide a short reverberation time and freedom from echo without the use of special absorbents. The general shape of ceiling in cross-section is seen to be such as to direct first reflections generally towards the audience, and the fan-shaped plan serves a similar purpose. The authors also had in mind that in cinemas, sound is in any case sent towards the audience by the loud-speakers. The back wall, which could have been the source of a dangerous reflection, is well broken, and the ceiling is serrated to help dispersal. Another aim, in this particular case, was to make certain that the reflected sound came from an angle not too greatly divergent from the line of direct sound—a point which they had noted as a factor in cinema " intimacy."

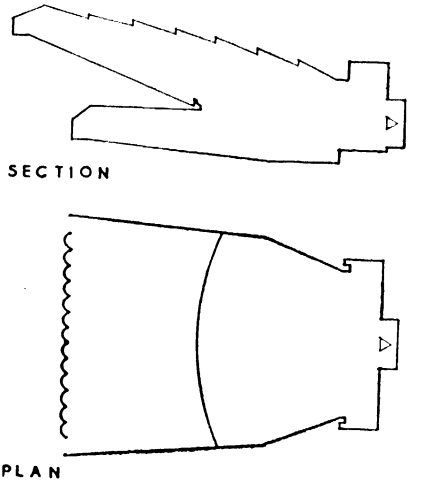


Fig. 18. PROPOSED DESIGN FOR CINEMA BASED ON ACOUSTIC PRINCIPLES
(Mason & Moir)

210. At the same time, one serious risk is attached to the use of auditorium shapes of this general type in some circumstances. The direct sound going towards the audience will meet a certain number of reflectors such as gallery fronts, the risers of steps in the aisle, empty seats, and the audience itself, which is not entirely absorptive; in addition the rear wall, even broken and treated with an efficient absorbent, will reflect a remainder of sound which, owing to its large area, may amount to a great deal. The reflected sound may then return to strike the splayed side walls and ceiling, whence it finds its way towards the front of the house some time after the direct sound has passed these seats, and it is then observed as an unexpected revival of reverberation, or even as an echo. This is all the more noticeable if the front seats are below the level of the source and receive the direct sound weakly, a point which was mentioned in paragraph 195. Bagenal notes that many complaints in modern theatres can be traced to this, and suggests that the splays near the proscenium, which are the main cause of the trouble, should be made absorbent, or treated to diffuse sound—a function which used to be

served by proscenium boxes and the frequent use of heavy decoration, now less common. Some such treatment might be suggested as an amendment to the plan illustrated.

211. Fan-shaped halls as described above tend to have a short reverberation time, simply because so much sound is absorbed quickly by the audience. In fact, it would be almost impossible to develop the long reverberation time and smooth decay of sound which is desirable for music, and auditoria of this type have not been found very satisfactory for this purpose. This cuts across some modern design practice in which these highly corrected shapes are used for all purposes; the importance of the point should therefore be emphasized. It is probably better for music to employ a rectangular shape with a ceiling which, broadly speaking, is horizontal, and walls which are at least in part parallel. Sound will then play between the various surfaces for a longer time, so that reverberation can be developed. It is significant that of the fifteen halls which Bagenal and Wood have analysed [1] and found good for instrumental and choral music, the great majority have this characteristic of being generally rectangular in form. This is not to suggest that the fan-shaped plan is entirely to be avoided for music, but it would be improved by parallel panels on the side walls. Bagenal has made some suggestions,[2] of which one is shown in Fig. 19.

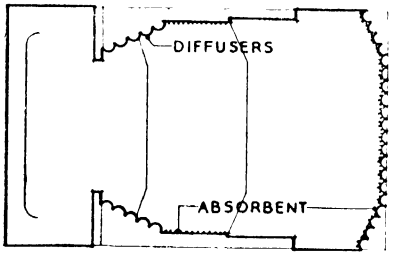


Fig. 19.
SUGGESTED MODIFICATION OF FAN-TYPE PLAN FOR CONCERT HALLS (Bagenal)

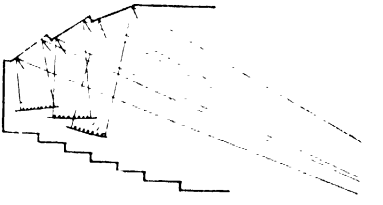


Fig. 20.
REINFORCING SOUND IN DISTANT SEATS

212. The use of diffusers on the proscenium splay and the back wall should be noted, and the absorbent on one of the side panels on each side. This follows the idea of distributed absorbents, though the suggestion of symmetry in this respect should not be read literally.

213. One other factor Bagenal has noted as able to contribute to the reinforcement of sound, and that is to locate a reflector, preferably a resonant and polished panel of some kind, on the floor in front of the performers. Sound striking this is sent upwards towards the ceiling, and thereby helps distribution

214. The third function of reflected sound is to strengthen tone in distant seats. This is arranged usually by designing some part of the ceiling near these seats as a directional reflector. A concave curve may be used, or a series of splays which concentrate the sound, for the difference between the length of direct and reflected paths will not be serious here. An example is shown in Fig. 20. These reflectors should be hard and highly finished, so that they function with the maximum of efficiency, especially for high frequency sound, which will otherwise tend to be weakest in these seats. It is, of course, essential to avoid designing alcoves or other shapes so that there is a risk of adding to reflections going back to seats near the stage, especially in theatres.

[1] Bagenal, H., and Wood, A., *Planning for Good Acoustics*, pub. Methuen, 1931.
[2] Bagenal, H., *Practical Acoustics and Planning Against Noise*, pub. Methuen, 1941.

215. An analysis of the movement of the direct sound and at least the first reflections should be made for every auditorium, as a routine check in its performance. A method of graphical analysis is outlined in Appendix IV.

ABSORPTION OF SOUND

CALCULATION OF REVERBERATION TIMES

216. A number of references have been made to reverberation and reverberation times in auditoria. The reverberation time is the interval between the stopping of the source and the moment when the subsequent reverberation dies away to inaudibility.[1] Its length is a useful guide to the acoustic suitability of a hall.

217. It will be apparent from what has been said previously, that if the sound is reasonably dispersed, the reverberation time will depend upon the size of the room and the amount of absorbent in it. The size or volume comes into the relationship because it is a guide to the total length of path for sound reflected from one surface to another; the larger the hall, the longer the paths must be on the average, and therefore the longer the reverberation time. The absorption is a factor, because upon it depends the amount of energy extracted from the sound waves as they strike the various surfaces.

218. The relationship was first examined about 1900 by W. C. Sabine, who found that the reverberation time in a room could be predicted fairly accurately by using the following simple formula:

$$T = \frac{\cdot 05V}{A}$$

where T is the reverberation time in seconds,
V is the volume in cu. ft.
A is the product of the area of absorbent and the coefficient of absorption in sq. ft. units.

Subsequent refinements have added to this formula, but in the form given it is still employed for common practice, and can be taken to apply to all rooms where sound is dispersed reasonably well. For auditoria which are shaped to send a powerful first reflection to the audience, such as are described in paragraphs 209 to 211, the reverberation time will be somewhat shorter than would be indicated by the formula.

SOUND ABSORBENTS

219. The absorption " A " in the formula is determined by multiplying the area in sq. ft. of each type of surface in a room by its absorption coefficient, and adding the results together. Allowance for such items as furniture and occupants is usually made individually, though sometimes audiences are calculated as absorption per sq. ft.

220. Broadly speaking, there are four types of sound absorbents of which account has to be taken.

Group 1. This group contains the standard building finishes, such as brickwork, concrete, wood flooring, plaster on brick, and similar materials, whose absorption is low. Some representative materials in this group are shown below, where it will be seen that they absorb only from 1 to 5 per cent of the incident sound, *i.e.* their coefficients range from ·01 to ·05 at nearly all frequencies. It will be found that in a room where no special absorbents are employed, a first rough estimate of the length of reverberation time can be found quickly by assuming that walls, floor, and ceiling all have an absorption of about ·03. All that need be done then to get " A " is to calculate the total area of the walls, floor, and ceiling in the room, and multiply by ·03.

[1] Or more specifically, the time taken for sound to decay 60 db.

TABLE IX. ABSORPTION COEFFICIENTS OF STANDARD BUILDING FINISHES

MATERIALS	ABSORPTION COEFFICIENTS 125 c.p.s.[1]	500 c.p.s.	4000 c.p.s.	REMARKS
Group I				
Brickwork, unpainted	·024	·03	05 *	
Brickwork, painted	·012	·017	·025 *	Note loss of absorption.
Concrete or terrazzo	·01	·015	·02 *	
Polished stone or tiles	·01	·01	·015 *	
Plaster, gypsum, or lime (on brick)	·013	·025	·045 *	Note lime and gypsum plaster similar.
Wood flooring (on battens)	·05	·03	·03 *	More absorbent at low frequency due to space beneath (see Group III).
Lino (on concrete)	·02 *	·03	·05	

* Figure deduced, and only approximate.

Group II. The second group of materials includes the great variety of special acoustic absorbents which have been put on the market in recent years. They include such materials as felts, asbestos, fibreboards, and special plasters. Their efficiencies are often rather low at low frequencies ranging perhaps from 5 to 10 per cent but can be increased by increasing thicknesses. They rise rapidly with increasing frequencies, and at 500 c.p.s. or upward, efficiencies of from 60 to 90 per cent may be reached. The plasters, generally speaking, have somewhat lower values than these figures at the different frequencies. In addition, their performance is variable, depending quite a lot on the skill of the workman. Nevertheless they are very useful and attractive.

TABLE X. ABSORPTION COEFFICIENTS OF SPECIAL ABSORBENTS

MATERIALS	ABSORPTION COEFFICIENTS 125 c.p.s.	500 c.p.s.	4000 c.p.s.	REMARKS
Group II				
Fibreboard tiles, perforated—½-in. thick on solid	·07	·57	·63	Note relative efficiencies at 125 and 500 c.p.s.
Fibreboard tiles, perforated—1¼-in. thick on solid	·13	·99	·5	
Fibreboard, ½-in. on solid	·05	·54	·6	
Carpet	·09	·21	·37	
Acoustic plaster (assumed on solid)	·13	·37	·58	
Curtains—light, 10 oz./sq. yd.	·04	·11	·3 *	
heavy, 18 oz./sq. yd.	·10	·50	·90 *	
Felt, 1-in. thick	·10	·52	·44	
Asbestos spray, 1-in. thick	·25 *	·70	·61 *	

* Figure deduced, and only approximate.

The absorption depends somewhat on the thickness of the absorbent, being greater the greater the thickness, especially at low frequencies.

Some of these materials are relatively soft and have to be used where they will not be damaged. Some are marketed with special protective coverings such as

[1] c.p.s.=cycles per second.

perforated metal, and perforated plywood and hardboard has also been used; the latter have very little effect on low and middle frequency absorption, but cause a reduction at high frequencies, which may be useful, as will be seen later.

Decoration of absorbents in this group has to be undertaken with care, for their value depends on their porous surface, and a treatment by painting or distempering may lead to greatly reduced absorption. The manufacturers will usually supply directions for decorating, or self-colour the materials themselves.

Group III. The third group consists of panels which absorb by resonance; they function principally in the lower frequencies. It is less the nature of the material than the method of mounting which enables them to absorb. The frequency at which they will reach their best absorption depends partly on the depth of air-space behind the panel and on its unit weight and stiffness, increases in each being accompanied by a lowering of the frequency. This type of absorbent has only quite recently been given serious attention, and only a relatively few measurements of absorption have been made, some of which are quoted in Table XI. All materials which can be mounted in panel form can be made to absorb in this way, including plaster on lath, plasterboard, hardboard, plywood, and the fibre-boards, whose efficiency at higher frequencies has already been noted. The absorption at the low frequencies can be made more effective by putting absorbents into the inter-space. At higher frequencies the panels will not usually absorb more effectively than their surface and porosity would indicate, but it will be seen later that there are advantages in having relatively less absorption at high frequencies.

Another characteristic of panels should be noted. When they are induced to vibrate by resonance, they themselves become sources of sound and add to the general loudness. Only when the source is stopped and they receive no more energy do they become absorbents in the accepted sense.

TABLE XI. ABSORPTION COEFFICIENTS OF PANELS

MATERIALS	ABSORPTION COEFFICIENTS 125 c.p.s.	500 c.p.s.	4000 c.p.s.	
Group III				
3·5 mm. hardboard, 1 cm. air-space	·01	·17	·07	
3·5 mm. hardboard, 3 cm. air-space	·12	·15	·15	Observe increase in efficiency at low frequencies as air-space increases.
3·5 mm. hardboard, 5 cm. air-space	·23	·15	·05	
3 mm. plywood, 5 cm. air-space	·25	·20	·10	
3 mm. plywood, 5 cm. air-space with 7 cm. wadding around edge of interspace	·42	·20	·13	Observe increase in efficiency at low frequencies as absorption in interspace is increased.
3 mm. plywood with air-space filled with wadding	·70	·25	·13	
Fibreboard tiles, 1½-in. thick, 1-in. air-space behind	·28		·49	Cf. same material in Group II.
Fibreboard, ½-in. thick, 3-cm. air-space	·33		·45	Cf. same material in Group II.
Acoustic plaster, ½-in., on ¾-in. backing, with 1-in. air-space behind		·40	60	Cf. same material in Group II.
Plaster on lath	·02	·03	·05	
Glass	·035	·027	·02	

Group IV. In this group are found furniture and occupants, allowance for which is usually made in terms of the absorption per unit. The tabulation of typical coefficients of absorption for soft furnishings offers some difficulty, because of the great variability in upholstering, but the range has been indicated by selected items in the Table. Where large numbers of seats are to be used, they will form a substantial part of the total absorption, and the manufacturer should then be asked to supply absorption coefficients. For large numbers of seats it would be best to get an absorption figure per sq. ft. of seating area, rather than for a single chair, because in groups the chairs will shadow one another slightly and the floor on which they stand. The coefficient obtained in the laboratory should be taken on a group of seats, standing on the type of flooring to be used. Then, in calculating the absorption, the seating area is simply assumed to be an absorbent surface.

Hard furniture is less variable in absorption and typical items are given.

TABLE XII. ABSORPTION COEFFICIENTS OF INDIVIDUAL ITEMS

MATERIALS	ABSORPTION COEFFICIENTS			REMARKS
	125 c.p.s.	500 c.p.s.	4000 c.p.s.	
Group IV				
Audience per person, adult, seated	3·6	4·7	4·9	W. C. Sabine's figures. Laboratory tests; occupants on hard pews.
Audience per person, adult, seated	1·1	3·2	4·5	Average recent figures quoted by P. E. Sabine. Occupants in upholstered theatre chairs, in laboratory.
Audience per person, adult, seated	1·0–2·0	3·0–4·3	4·0–6·5*	Figure to be taken depends on nature of seating (Acoustical Materials Association of America).
Audience per person, adult, seated	5·0	5·4	9·7	Mason and Moir's figures, based on laboratory results and theatre tests; occupants in theatre seating.
Audience, per sq. ft.	·5	·82	1·0*	Chrisler's figures, given in terms of sq. ft. units.
Seat, plywood and wood frame	·15	·17	·38*	
Seat, leather upholstered	1·2	1·6	2·1	
Seat, heavily upholstered, soft finish	2·8 *	3·0	3·6	

* Figure deduced, and only approximate.

221. The occupants of an auditorium will normally provide the most important area of absorbent, and special care is required, therefore, to get the figure as accurate as possible. One point should be specially noted, that when a seat is occupied, both the occupant and the seat have individually less effect as absorbents, due to the coverage of one by the other, for the back of the occupant and the front of the seat cease to be operative. In practice it is usual to assume that the total absorption value of chair and seated occupant is, in fact, only equivalent to that of the occupant alone. Nevertheless, this will not always be true, and if a case justifies requesting the manufacturer to supply an absorption coefficient for seating alone, he should also be asked to supply a figure for the seating when occupied.

222. There is unfortunately some disagreement among authorities as to the exact absorption coefficient to be taken for audience; the figures which have frequently been used were originally obtained by W. C. Sabine, at a time when measurement was less accurate than now, and clothing was different too. Later figures have been suggested, but there is no agreement regarding seating for tests, nor is there known to be any correlation of the figures with practice, except those of Mason and Moir. These, however, were taken in a theatre where the sound was directed at the audience, so that the figure is high for general use, but probably suitable for cinemas, where the loud-speakers send the sound to the audience. The range of disagreement is substantial, and it would be of the greatest advantage to have agreed figures. The Committee suggests, pending such an agreement, that the figures given by the Acoustical Materials Association of America should be used.

223. In addition to the absorbents listed above, account must be taken of the absorption by air of high frequency sounds. Up to the region 1000 to 2000 c.p.s. the loss is not great enough to need attention, but at higher frequencies it will be very considerable. For a frequency of 4000 c.p.s. the approximate absorption, in sq. ft. units, is equal to ·01 times the volume of the room. Thus a room of 10,000 cu. ft. would provide 100 units of sound absorption for a frequency of 4000 c.p.s.,

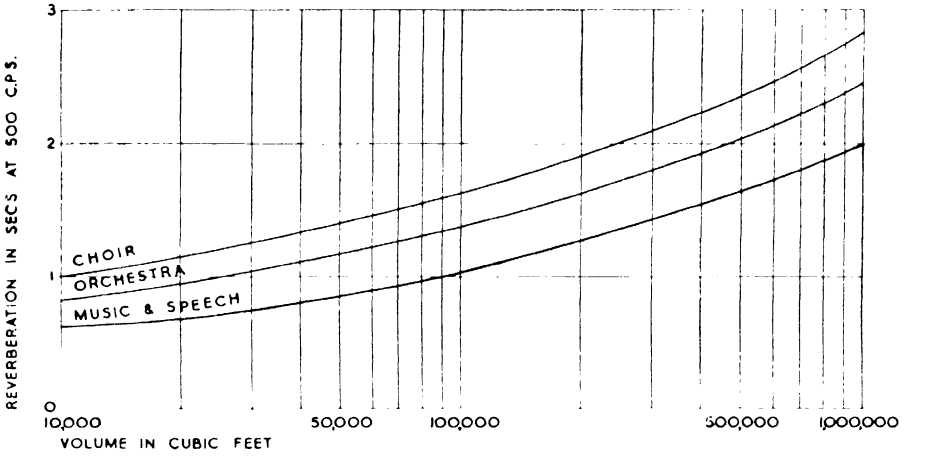


Fig. 21. OPTIMUM REVERBERATION TIMES

due to the volume of air. These 100 units would simply be added in with other absorbents to give " A " in the formula, when the calculation for the reverberation time at 4000 c.p.s. is made.

224. It has already been mentioned that absorbents other than the audience—should be well distributed in the room. This ensures that the sound will, on the average, fall upon them sufficiently often for them to be effective. One danger of concentrating large areas of absorbent in one part of a room is that the reverberation time in that part of the room will be lowered, so that the room as a whole acquires different characteristics, in different places, some "live" and some "dead." This is usually undesirable, with the exception that the region around the source should always be strongly resonant. No unnecessary absorbent should be placed there, and in particular, an attempt should be made by the use of polished surfaces to maintain the best possible reflection of high frequencies. These are very important for the proper hearing of consonants and "s" sounds in speech, which are important to intelligibility, and hardly less so for good tone in music. The fact that they are strongly absorbed in air suggests that every other means of maintaining their

strength should be sought. Panelling is useful in the region of the source because of the reinforcement it provides by resonance. Another place which should not be too absorbent is the region beneath a gallery; it usually has a much smaller volume, and the reverberation times will tend to be short in any case.

OPTIMUM REVERBERATION TIME

225. When the reverberation time has been calculated for a room, it is necessary to have some standard by which to judge whether it is or is not suitable. Experience in this field has been carefully recorded, and there are now curves showing what the optimum times should be for halls of different purposes and volumes. These are shown in Fig. 21.

226. The above curves all relate to the optimum time at one frequency, 500 c.p.s., which represents "middle pitch." It will be obvious, however, that the reverberation at high and low frequencies is no less important. The relation between the three regions of pitch has been considered on theoretical grounds and examined in practice, and the conclusion was reached that the reverberation time should be about 50 per cent greater at low frequencies than at "middle pitch," and also a little greater at high frequencies as well, if this is possible. This would give a reverberation frequency curve very roughly as indicated in dotted lines in the next diagram. In view of the limited data available on absorption by vibrating panels, the calculation at the lowest frequency is not readily carried out at the present time, but it should be attempted; the other two should certainly be done. Where a hall of musical importance is under consideration, calculation of all three is important. Suitable frequencies at which to make calculations are 125, 500, and 4000 c.p.s., for which the data in this Report are given.

EXAMPLE CALCULATION OF REVERBERATION TIME

227. The analysis of reverberation times can be conveniently illustrated by an example.

A hall of rectangular shape, for which no specific acoustic treatment has been suggested, has a volume of 100,000 cu. ft., and is to seat 500 people.

The absorption in the room is given in the following Table:

TABLE XIII. SCHEDULE OF ABSORBENTS IN EXAMPLE AUDITORIUM

ABSORBENT	ABSORPTION 125 c.p.s.	ABSORPTION 500 c.p.s.	ABSORPTION 4000 c.p.s.
Walls, plaster on brick, 7200 sq. ft.	7200 × ·013 = 94	7200 × ·026 = 180	7200 × ·045 = 320
Ceiling, plaster on lath, 3200 sq. ft.	3200 × ·03 = 96	3200 × ·03 = 96	3200 × ·045 = 140
Doors, 250 sq. ft.	250 × ·08 = 20	250 × ·06 = 15	250 × ·06 = 15
Stage floor, wood, 800 sq. ft.	800 × ·05 = 40	800 × ·03 = 24	800 × ·03 = 24
Aisles, carpet, 600 sq. ft.	600 × ·09 = 54	600 × ·21 = 120	600 × ·37 = 220
⅔ audience, seated	330 × 1·1 = 360	330 × 3·2 = 1060	330 × 4·5 = 1500
⅓ seating, empty, leather upholstered	170 × 1·2 = 200	170 × 1·6 = 270	170 × 2·1 = 360
Air, 100,000 cu. ft.			100,000 × ·01 = 1000
Total Absorption "A"	= 864	= 1765	= 3579

Using the Sabine formula, $T = \frac{\cdot 05\ V}{A}$, it is found that the reverberation times at the three frequencies are respectively 5·8 sec., 2·9 sec., and 1·4 sec. The rise at the low frequency end is excessive, and the drop at the other end is serious.

The optimum reverberation time at 500 c.p.s., as indicated by the curves given in paragraph 225, are from 1·1 to 1·7 sec. depending on the purpose of the hall. It is apparent, therefore, that the reverberation time of 2·9 sec. at middle pitch is excessive.

Several alternative courses are open to a designer. Perhaps the most obvious would normally have been to employ one of the special acoustic absorbents, such as are given in Group II. Let us consider the case of an acoustic plaster to be applied to the walls; the coefficient for the plaster at 500 c.p.s. will be 0·37. If the reverberation time at 500 c.p.s. is to be brought down to 1·7 sec.—the top limit—then it can be calculated from the Sabine formula that about 1200 more absorption units are required. At a coefficient of 0·37, 3200 sq. ft. of the absorbent plaster would be needed to give this, without making allowance for the loss of the trifling absorption formerly provided by the hard plaster on the area to be replaced. Then the reverberation times at the other two frequencies have to be re-examined and are found to be respectively 3·9 sec. for the low, and ·9 sec. for the high. The curve for this treatment may be compared with the first one, in Fig. 22, and with the desirable curve, shown as a broken line. It will be seen that although at 500 c.p.s. the reverberation time agrees with the ideal, it is still badly at variance at each end.

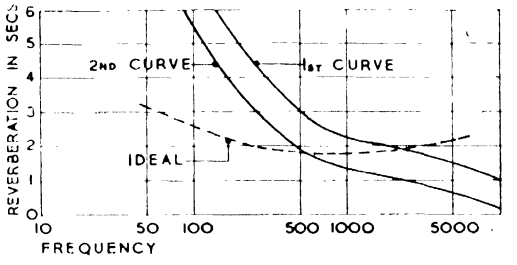


Fig 22. REVERBERATION TIME CURVES

Considering the curves in detail, it is apparent that what is wanted at high frequencies is not an increase of absorption, but some way of actually decreasing it below what it originally was calculated to be. Obviously, then, what should be sought is an absorbent functioning at low and middle pitch only, which means that one of the panel absorbents might prove most suitable. In Group III are shown the coefficients for 3 mm. plywood spaced 5 cm. from the wall. The coefficient at 500 c.p.s. is ·20, and if, as noted above, 1200 units are required to bring the time down to 1·7 sec., then 6000 sq. ft. of panel treatment will have to be used. This would have the effect of bringing the other two frequencies down to 2·2 sec. at 125 c.p.s. and 1·3 sec. at 4000 c.p.s.

This is a much improved curve, but still drops at the higher end, and some way has still to be found of reducing the absorption at 4000 c.p.s. The plywood panelling which has been suggested was apparently tested bare, so that the exposed grain is probably causing exceptional absorption at high frequencies. The supposition is supported by considering the hardboard, which is smoother, though comparable in other respects; its absorption at this frequency is 0·5, only half that of the plywood. There is little doubt in fact that by using a highly finished surface, by painting or polishing, the coefficient could be reduced to, say, the figure for linoleum, which is ·03. This would have the effect of raising the rever-

beration time at 4000 c.p.s. to 1·5 sec., which appears to be as high as would be practicable in this case. The curve is shown in Fig. 23, along with the ideal.

228. An important deduction to be made from this example, which is typical, is that it is very difficult to conserve the high frequencies. Even by reducing the volume of the room, in this case, relatively little can be done. But certainly, in such cases, it is desirable to avoid unnecessary volume and absorbents which add to the absorption at high frequencies. If it seems otherwise necessary to use the porous materials which are effective in this range, then they might be given some such covering as perforated plywood, which will reduce the top absorption without much affecting the other ranges.

229. This emphasizes a second point, that panel absorbents may in future play a most important role in acoustic design, because of their range of efficient absorption. The example shows clearly how useful they may be.

It should be mentioned that the very limited range of panel absorbents given in Group III is not adequate for general use in design. It can be calculated, for instance, that 5 mm. plywood, spaced 2·5 cm. from the wall, would have its best absorption in the middle range, where it is most wanted, but we do not know what that absorption would be. If by using porous absorbents in the interspace, its efficiency could be made to reach, say, ·4 or ·5, the area of treatment required in the case above would be halved. Further research in this field is urgently needed, and will be discussed in Part III of the Report.

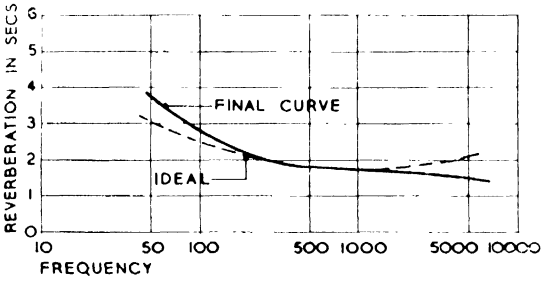


Fig. 23. REVERBERATION TIME CURVES

230. A third point is that the audience is the dominant absorbent. This being the case it emphasizes how desirable it would be to have an agreed figure, known to have a close approximation to practice.

231. Volumes of 150 to 200 cu. ft. per person are suitable targets for purposes of initial design, so far as acoustics are concerned, for halls of moderate size.

THE TREATMENT OF INDIVIDUAL AUDITORY TYPES

AUDITORIA FOR MUSIC

232. In designing auditoria for music, it should be appreciated that the performers are dependent, in the end, on the acoustics of the room for the manner in which they are heard by the audience. The quality of one loses by a poorer quality in the other, and these rooms should be given the best conditions possible, equal, in fact, to the care taken in the making of instruments, and the skill of the performer.

233. The optimum reverberation times for auditoria for music, especially choral music, are somewhat longer than for speech, as shown in Fig. 21, and it is important to tonal quality to maintain both the low and high frequencies. Reverberation should be calculated at the three regions of pitch. 125, 500, and 4000 c.p.s.

234. The seating arrangements for performers require special attention. Numbers of players ranging from one or two soloists up to large choruses usually have to be accommodated in the same hall at different times, and it is most desirable that some flexibility be given to the arrangement so that a quartette or chamber orchestra need not sit in the emptiness of unoccupied orchestra and chorus seating. Suitable movable reflectors should be provided which could be adjusted.

235. In the arrangement of the platform seating, each cello and double bass player should be placed so that his instrument is visible to the audience. Brass should be relatively screened, if this is possible. A customary arrangement is to have the smaller stringed instruments in benches of three or four players, set on the flat forepart of a raised stage. This can be criticized on the grounds that those of the audience who are nearest cannot hear a full body of string tone, owing to the masking of instruments behind the front row; nor can they hear properly some of the other instruments, owing to the fact that the sound is projected over their heads. It would appear to be a more logical and satisfactory arrangement to forgo the raised stage, and commence the seating at floor level. Then if the audience seating is well ramped, as it should be, all will have a full view of the orchestra, even if the strings remain in benches on the flat part of the floor. The diagram longitudinal section (Fig. 24) illustrates the point.

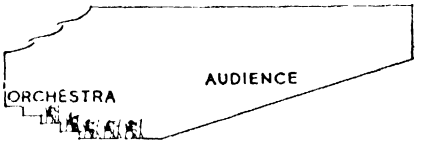


Fig. 24. DIAGRAM CROSS SECTION SHOWING RAMPED ORCHESTRA SEATING DOWN TO FLOOR LEVEL

236. The provision of concert organs is often treated as an inconvenient necessity and it is sometimes undesirably cramped. The instrument should speak as freely as possible into the room, and be surrounded by hard, reflecting surfaces. It should, of course, be near the orchestra.

237. Much has already been said regarding the shape of the hall. To-day, many architects favour the shell-shaped hall, or at least the fan-type plan. It has been observed, however, that in these rooms the reverberation time is often too short. It is important, therefore, that the modifications necessary to make such plans suitable for music be considered by architects. The services of a consultant are advised in cases of important concert halls.

AUDITORIA FOR SPEECH AND DEBATE

238. In auditoria for speech and debate, the first object is intelligibility, which depends firstly on a short reverberation, and secondly on the high frequency speech components.

239. Short reverberation may be obtained through a number of factors, one of which is to have a low volume—150 to 200 cu. ft. per person, depending on whether the hall is small or relatively large, seating, say, 2000 or more. Another factor is the use of adequate absorption, though the necessity of maintaining high frequencies points again to the use of panel absorbents. A third factor is the shape of the hall, for it has been seen that by shaping the walls and ceiling rather like a shell or megaphone (where the rostrum plan is required), assistance can be given to the speaker's voice, and at the same time reverberation can be reduced by

sending the sound directly to the audience. It is useful in this case to install well-upholstered chairs, so that whether the seats are occupied or not will make little difference to the acoustic quality of the room.

240. Mason and Moir (*loc. cit.*) have shown that a room of this kind should need little or no special sound absorbent, except to reduce dangerous reflections on, say, the back walls or proscenium splays, and it might, therefore, be considered as a rule-of-thumb method of design for speech auditoria. It would be well to check design, however, by the Sabine formula, recognizing that it will predict a longer reverberation than will probably be found in the completed hall.

241. In view of the relative weakness of the human voice a good direct path for sound from speaker to listener is important. This raises special problems in legislative chambers and auditoria for debate, because the position of the speaker cannot be anticipated and reinforced. This has a direct influence on planning. For instance, in a chamber holding 300 or 400 people, such as the House of Commons, there will always be a percentage of listeners behind a given speaker. These receive the direct sound poorly, and must rely largely on good reflection, particularly from surfaces on the opposite side of the room. This means that width is limited, or the reflection will become an echo. The larger auditoria of this type, for City Councils, County Councils, and the larger legislatures, offer very difficult problems which call for the utmost care, skill, and forethought in treatment, and remain one of the most frequent sources of acoustic failure to-day. The advice of consultants will be desirable in these cases.

242. A more detailed analysis of treatment for halls of this type has been made by Bagenal (*loc. cit.*), who has successfully employed curved seating plans, and inward tilted side walls as reflectors.

243. In most large council rooms, some provision for the press has to be made. Where members address a chairman, it can be taken as a desirable point of planning that the press should be near him, and not so far above, or even to either side, as to be out of the line of speech from the members. In large council chambers, the press table might be on the floor of the house near front benches.

244. Small council and committee rooms unexpectedly often present difficulties which sometimes can be traced to an ill-shaped table round which the members sit. A long oval or rectangle is popular but is undesirable acoustically. All seated at the table should be able to see one another easily, which means rather more open arrangements, such as the " horse-shoe," which is probably one of the best.

AUDITORIA COMBINING SPEECH AND MUSIC

245. There are three auditorium types combining music and speech—the theatre, the general purpose hall, and the church.

THE THEATRE

246. The modern theatre is usually designed on the fan-type plan, as compared with the earlier "horse-shoe" designs, and though it provides generally better sight lines for a large number of seats, the greatly extended rear wall, often curved in plan, together with the total of risers from the curved and ramped seating, tends to give a large echo-producing area which concentrates sound towards the front of the house. The splayed side walls and proscenium may contribute to the effect by gathering up the sound, and suggests one cause of the complaints which frequently come from occupants of front seats. The raised stage would not help because of the tendency of performers to direct their voices upwards.

247. The remedies appear to lie firstly, in providing the rear wall with diffusing surfaces and absorbents, and preferably, in making it straight instead of curved. Secondly, the splayed side walls of the proscenium arch should be similarly treated in some way, and the arch itself, overhead. (See Fig. 19.) Finally, careful consideration should be given to lowering the stage level in relation to the front seats. A case which may suggest a solution to the stage problem is found in the Wagner Theatre at Bayreuth, where stage and seating are on the same level (Fig. 25).

248. While all these suggestions will be useful for any type of theatre they are essential to good performance of music-hall and variety, in so far as rapid repartee requires absolute clarity and very short reverberation.

THE GENERAL-PURPOSE HALL

249. The general-purpose hall has usually two distinguishing characteristics which give rise to acoustical problems. The first is the flat floor, required for many functions, and the second is the combined theatrical stage and concert platform.

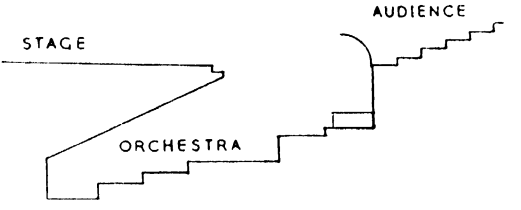


Fig. 25. EXAMPLE OF STAGE AT SAME LEVEL AS AUDIENCE SEATING
(Bayreuth Theatre)

250. The flat floor results in bad sight lines for the audience, and consequently, in bad hearing conditions. If possible, at least the rear part of the hall should be permanently ramped, or provision made for removable ramped seating, though no really satisfactory form of temporary ramped seating is available on the market. If it is absolutely impossible to provide any ramped seating at all, then the utmost use should be made of directional reflectors, both on the walls and ceiling.

251. The combined concert and theatre stage is most unsatisfactory. It makes for a bad theatre, and worse musical tone. The two are, therefore, incompatible. Where it is impracticable to avoid making the one chamber serve for both, the best treatment is to make adequate provision for equipping the theatre stage with the proper reflectors required for the various types of musical performance. A fore-stage is important.

CHURCHES

252. Acoustic complaints in churches are commonly due to reverberation caused by the relatively large interior volume and small amount of sound absorption. Where high vaults, domes, and deep transepts exist, there is also danger of echo and local reverberation. Therefore the planning of the building to form, as much as possible, a single cell, and to a moderate height, makes easier the acoustic problem but will not of itself give good acoustics. Some sound-absorbing treatment is generally required, and it should be located so as to give maximum effect. The "west wall" is usually a good position, and the nave roof has often been treated with success. An economical type of roof giving some absorption is the ordinary principal and purlin timber roof, having panels of materials such as fibreboard or wood-wool board fixed to the underside of the rafters. Open textured plasters and porous bricks and tiles will contribute some slight absorption if left undistempered.

THE TREATMENT OF INDIVIDUAL AUDITORY TYPES

253. The reverberation to be aimed at must depend on the type of service. Choral music and organ playing must be considered in addition to the preaching voice, so that the reverberation must often be a compromise. Very roughly, for an Anglican parish church seating 600, the calculated reverberation with a fairly full audience could be as much as $2\frac{1}{2}$ sec. For a Free Church of the same size, where greater emphasis is placed on the pulpit, a figure at $\frac{1}{2}$ sec. less would be more appropriate. Where a church is too "dead," unaccompanied singing is impossible. A successful compromise has been made in which the nave is more absorbent for pulpit requirements, and a chancel with a vault gives conditions more suitable for music. A west gallery is desirable from an acoustic point of view. It should be noted that "sound boards" over pulpits are only useful in lofty churches where reverberation is long: under such conditions they serve to cut off the upward sound, and if they have a wide "spread" can effect a slight improvement

ELECTRICAL SOUND REPRODUCTION

254. This involves many problems of a rather special character which we have not included in our Report.

PROBLEMS OF NOISE REDUCTION

255. In such places as offices, factories, and restaurants, the acoustic problem is primarily one of noise reduction alone. The annoying part of noise is often traced to its higher frequencies, and special attention should, therefore, be devoted to reducing these by absorbents, though care should also be taken, of course, to select quiet machinery, and in other ways to reduce the noise at the source. On the whole, it is probably best to put sound absorbents on the ceiling in large rooms, and all else being equal, the sound reduction can be made more effective by keeping the ceiling low. In selecting absorbents for this purpose, it should be kept in mind that a good light reflection factor is a desirable characteristic for a ceiling to have.

SCHOOLS

256. The modern school classroom, about 25 ft. square and 11 ft. high, finished in plaster, will have a reverberation time, empty, of 4 or 5 sec., which will be reduced to about 2 sec. when 40 pupils are present. These figures are excessive and result both in high general noise levels in the classrooms and in reduced intelligibility for the children. We do not think reverberation times should exceed 1 sec. at 500 c.p.s., and the classrooms should accordingly be given the necessary corrective treatment. In a typical classroom, this could be effected by applying an absorbent with a coefficient of the order of ·3 to the ceiling.

257. Corridors in schools also require attention to attenuate sound transmission along them. This can probably best be effected by placing occasional areas of absorbent on the walls and ceilings. This would be especially important in corridors connecting noisy and quiet zones in schools.

258. Gymnasia should also be given noise reduction treatment.

FACTORIES

259. Factories have widespread problems of noise reduction, to which we attach the greatest importance, but of which we are unable to make a thorough investigation at the present time. Cases have been quoted of certain noisy industries having a permanent effect on the hearing of operatives, which suggests that the value of sound absorbents in this connection must be ranked high, and even where the noise may not be sufficiently great to result in permanent deafness, it will markedly reduce efficiency. We feel that this problem merits a special investigation.

RESTAURANTS AND CANTEENS

260. We need only remark on these to the extent of saying that they are frequently noisy, and that part of the noise is due to hard table tops, cutlery, and china. Compensation in form of effective sound absorption is nearly always desirable, though, naturally, quiet equipment is useful.

OFFICE BUILDINGS

261. It is desirable to call attention to a number of problems of noise reduction in office buildings.

262. Offices containing tabulators and other accounting equipment often require treatment to reduce noisiness, both from the point of view of leaving less noise to be transmitted elsewhere, and for the comfort, health, and efficiency of the operators. Ample areas of high efficiency absorbents should be employed, and are probably best applied to the ceiling. Several commercial firms are prepared to consult upon and undertake this kind of work.

263. Corridors should also receive attention, as noted earlier. Areas of absorbent should be applied to corridor walls and ceilings at frequent intervals, or preferably, of course, all the way along.

264. In offices for quiet, sedentary occupations, areas of absorbent should be located on the ceiling or walls where sound entering directionally from a street may first impinge and be absorbed.

THE HOME

265. The acoustics of rooms in homes do not usually give rise to complaint. Rooms may occasionally be over-absorbent if heavily upholstered furniture is used, but this may be considered a desirable feature in that it contributes to the reduction of noise. An over-absorbent room is undesirable for musical purposes, of course.

PART III. PROPOSALS FOR FUTURE RESEARCH AND INVESTIGATION

SOUND TRANSMISSION

266. Sound transmission has been the subject of research in comparatively recent years only. That it has reached the present stage where we can say which among modern constructions are good and which are bad, and in fact devise new treatments with some confidence, is gratifying. But there is still much to be learnt. The early work has been generally devoted to specific inquiries needing immediate attention, but they serve also to point the way to increasingly fundamental studies of the general mechanism of sound transfer. To these much importance must be attached, and they should be taken up as soon as it becomes practicable to do so.

267. In addition to such work on a laboratory scale, full-scale experiments under practical building conditions are essential. It is recommended that an early opportunity for such work should be provided by incorporating in Government subsidized buildings alternative methods for sound insulation, such as those recommended in the Report, and any new constructional methods which may be put forward and considered favourably in other quarters. This is particularly important in respect of housing. Only one of the treatments suggested in the Report has had full-scale trials, and modifications of the others may prove necessary.

RESEARCH AND INVESTIGATION

SOUND ABSORPTION

268. Several aspects of sound absorption require further study.

269. Recent theories of the mechanism of sound absorption by porous materials, which should assist in the development of such materials, require experimental checking.

270. Resonance absorption by vibrating panels offers a method of obtaining higher absorption at low frequencies, and more hygienic treatments than can be provided by porous materials. Some recent researches have been carried out on this aspect, but further work is required with a view to being able to tabulate absorption coefficients for an orderly group of panel thicknesses and mountings.

271. The absorption coefficient of an audience —usually the largest single factor in the reverberation calculation—is not known to a desirable degree of accuracy. Widely varying figures have been suggested, and more measurements are required under varying conditions.

272. An up-to-date table of absorption coefficients of materials employed in this country should be prepared and maintained by a suitable authority.

AUDITORIUM ACOUSTICS

273. A more precise knowledge of the characteristics of auditoria which are considered acoustically good is desirable. A comprehensive survey of auditoria with this in mind should be fruitful.

274. Electrical sound reproduction in auditoria of certain types, such as large assembly halls, cathedrals, and rooms for debate, gives rise to a number of problems of room acoustics which require further study.

NOISE

275. Effective planning and design with a view to avoidance of noise, requires a knowledge of noise conditions likely to occur in any situation. Field surveys are required to provide fuller information on this matter, and the following are suggested.

276. Measurements of traffic and other outdoor noises, to determine the general levels prevailing under different conditions, and the effect of reflection from neighbouring buildings, reverberation within streets, and reduction with increasing distance from the source. This is regarded as of primary importance and should, if possible, be carried out in the immediate future so that the results can be brought to bear on the redevelopment problems in good time.

277. Measurements of the prevailing and tolerable noise levels associated with various types of occupancy, domestic, scholastic, commercial, and industrial.

278. Data on noise in plumbing and the noisiness of service equipment in modern buildings is very deficient, and an adequate study of this field should be included in research after the war. If any steps could be taken in the immediate future, this would be desirable.

279. The development of quiet doors, door closures, and lift doors and gates, appears to call for special study.

PART IV. A SUMMARY OF STANDARDS AND TREATMENTS FOR SOUND INSULATION AND ACOUSTICS

We summarize our Report recommendations as follows:

SOUND INSULATION AND NOISE REDUCTION

HOUSING

280. Sound insulation should receive consideration as a factor in the zoning and siting of noisy industry, entertainment, and transport in relation to housing.

281. Some limitations on the proximity of domestic premises to transport routes (road and rail) are desirable. 150–200 ft. is suggested as a suitable figure for use where the site is level. More is desirable if dwellings are elevated in relation to the noise source and have a clear view of it.

282. Advantage should be taken of the value, from the point of view of quiet, of the cul-de-sac, and the aggregation of culs-de-sac which form what has been termed a super-block.

283. Planting of trees and shrubs is a useful adjunct in insulation.

284. The prevailing structural insulation is often inadequate in and between dwellings. The 9-in. party wall does not reduce sufficiently the noise of the radio next door, and does not insulate against some common impact sounds. In flats a higher standard for floors is necessary, and in all dwellings it is suggested there should be one quiet room. The following are recommended as minimum standards of sound insulation:

AIR-BORNE SOUND

a. Between the living rooms in adjacent dwellings	55 db.
b. Between the living room and other rooms other than service rooms within a given dwelling	45 db.
c. Between bedrooms and service rooms, and between the bedrooms themselves within a given dwelling	35 db.

IMPACT SOUND

Between any room in one dwelling and the bedrooms or living rooms of another dwelling adjacent beneath.	
Improvement on a bare concrete floor	15 phons.
Improvement on a bare timber floor	20 phons.

285. Indoor noises should be approached first as a planning problem, noisy and quiet parts being segregated. Between houses, the standard of air-borne sound could be satisfied by separating the living rooms in adjacent houses with stair-hall, garage, and service rooms. External screens should help to reduce sound transmission *via* open windows.

SOUND INSULATION AND NOISE REDUCTION

286. Three alternative structural treatments which should meet the standard for air-borne sound insulation between dwellings are described. Briefly, they are as follows:

a. The use of a cavity party wall (with no ties, or with wire ties only), and in the case of flats, continuing the cavity around the living room and combining it with a floating floor.

b. The use of protective linings on the walls and the ceiling, with a floating floor in the case of flats. This has the advantage and economy of added thermal insulation.

c. The use of lining on the party wall, and cutting the flanking walls where they meet the party wall.

SCHOOLS

287. The choice of site for a school is an important factor in quietness, particularly in urban districts where we emphasize the difficulty of devising any window treatment which will provide adequate insulation for classrooms facing main traffic thoroughfares. For schools, as for housing, some limitation on the proximity of classrooms and main thoroughfares is desirable. A distance of 100 ft. is suggested as a minimum. In urban districts it is clear that such a restriction must be difficult to achieve unless comprehensive land redevelopment is practised.

288. Within schools, the classroom block, where quiet is desirable, should be separated from the noisier rooms devoted to technical studies, manual training, exercise, and music.

289. The following are suggested as minimum standards of sound insulation for classrooms:

AIR-BORNE SOUND

Between classrooms and corridors, and between one classroom and another	45 db.

IMPACT SOUND

Between any classroom and a classroom beneath.	
Improvement on a bare concrete floor	15 phons.
Improvement on a bare timber floor	20 phons.

290. In addition, reverberation time in classrooms as calculated by the Sabine formula should be limited to 1 sec., at 500 c.p.s., the classroom to be assumed to have a full class present.

291. Quiet floor surfaces and floating floors should be used in corridors and lobbies opposite classrooms, and absorbents should be employed to reduce sound travelling in the corridors.

292. No special standards are envisaged between the noisier rooms as a group, but they cannot be neglected. For instance, a gymnasium over a lecture hall would create a most serious noise problem. Demonstration rooms, laboratories, art rooms, etc., are also sources of annoying impact sounds because of the continued movement of students.

OFFICE BUILDINGS

293. The common form of development in urban districts, whereby small properties are frequently rebuilt independently of neighbouring properties, means that offices and all other types of buildings are forced towards the street property

line and into a position where they are subjected to the worst of the street noise. Comprehensive redevelopment of urban districts under single control, and the use of other types of building plan, which would withdraw the building from the perimeter of the site, would seem to offer the best prospect of real improvement. If, for the accommodation necessary, such plan types would necessitate higher buildings, this would give a further improvement of quiet in the upper rooms. Height restrictions in this respect are undesirable.

294. Under all conditions the quiet side of the site should be recognized by designers as offering a first advantage in insulation; boardrooms and others needing quiet should be planned on that side.

295. The problem of traffic noise through windows is closely linked with ventilation. If open windows are relied upon insulation will be very small. If the system of air-to-air cross ventilation is adopted, then a natural air flow can be provided with relatively small window openings and with correspondingly greater sound insulation. Full insulation value in window design can only be had when they are kept closed and artificial ventilation is provided.

296. The following are suggested as measures of internal noise reduction in office buildings:

a. The use of quiet, resilient floor surfaces in corridors having an impact insulation value of the order of 10 phons.

b. The development and wider use of doors which are treated around the rebate to provide a quiet and effective closure.

c. The use of sound absorbent to reduce noise travel along corridors.

d. The segregation in plan of rooms containing mechanical accounting and tabulating equipment, and providing for them floating floors and sound absorbing ceilings.

HOSPITALS

297. With hospitals as for schools and office buildings great improvements would be possible if in land redevelopment the functional needs of the building could be the main factor in the choice of site. Considering that natural ventilation is desirable in hospital wards, it is evident that only sites whereon the wards may be adequately removed from main traffic thoroughfares should be developed for this purpose, and every ancillary aid to quiet, such as the use of noise barriers, planting, and height of buildings should be employed.

298. Within hospitals the zoning of noisy and quiet parts of the plan is a factor of prime importance in ensuring quiet where quiet is needed.

HOTELS AND HOSTELS

299. Hotels and hostels, like hospitals and schools, suffer from the restrictions of normal urban developments, and emphasize once again the need for functional considerations in land redevelopment.

FACTORIES

300. It is understood that noise in factories is the cause not only of reduced efficiency, but also in some cases of permanent deafness. This problem should well repay a fuller investigation than it has been possible to make in the present inquiry.

ACOUSTICS OF AUDITORIA

301. A general discussion of theory and practice is provided.

302. It is desirable in designing auditoria to make an analysis of the reverberation time at the following three frequencies, 125, 500, and 4000 c.p.s. Guidance is given on what the values should be at these frequencies for auditoria for music and for speech.

303. Auditoria for music, speech, the theatre, the church, and the general-purpose hall are discussed for their special problems.

G. B. SHARPLES, *Chairman.*
J. O. ACKROYD.
HOPE BAGENAL.
R. R. COSTAIN.
D. J. W. CULLUM.
GEO. D. MACNIVEN.
JOHN H. MARKHAM.
J. MCLAREN.
HENRY RICHARDS.
A. SCOTT
C. G. STILLMAN.
C. COWLES-VOYSEY.
WILLIAM ALLEN, *Secretary.*

APPENDIX I
NOISE IN PLUMBING

304. We have evidence, both from the Society of Women Housing Managers and from our own experience, that the noise of plumbing is one of the principal sources of nuisance in flats, and may also be a cause of annoyance in houses, hotels, and hospitals.

305. In flats and houses the noises of which complaints are made relate principally to the flushing action of the w.c., though the filling and emptying of baths and washbasins has been reported also as a trouble.

306. Two main lines of approach are open to the designer. The first is to use quiet equipment and a quiet layout. The second is to localize noise by keeping it out of the structure.

307. The first approach is fundamental, but will involve a certain amount of research and consideration of the manufacturers' problems, so that some time must elapse before it can be effectively used. This is especially true for low-cost work, since for the most part the quiet equipment available at present is fairly expensive. The Plumbing Committee is actively engaged on a study of this problem, and no doubt their work will eventually be embodied in suitable British Standards and Codes of Practice.

308. The second approach, though not fundamental in character, should have useful immediate results. The annoyance of plumbing noise in flats or houses arises mainly from its escape from the bathroom to other parts of the dwelling or to neighbouring dwellings, and it is clear, therefore, that if it can be kept out of the structure, and thus localized, much of its unpleasantness can be avoided. The w.c. is apparently the most important item. The cistern should be kept from rigid contact with the walls, resting rather on suitable buffers or pads, and the pan should be placed on some such material as cork or lino. The pipes running to and from both cistern and pan should be wrapped with tape, asbestos cloth, or

rubber, wherever they go through walls or floors, and holding clips should also be insulated.

309. The lavatory basin and bath are apparently less important items from the point of view of noise, and as it might be difficult to insulate the bath itself it seems reasonable to suggest that the communicating pipes only should be treated, by wrapping them, as before, where they come in contact with the structure. To keep noise from being transmitted from the pipes, *via* the fittings, to the walls, the taps might be insulated with cork or similar washers where they are fixed.

310. In hospitals and hotels, no doubt, the present types of quiet equipment can generally be afforded, but the principle of wrapping the pipes where they go through the structure should also be followed. However, there are also points about quiet layout to be taken into account, which will, no doubt, be the subject of comment by the Plumbing Committee.

APPENDIX II

SOUND TRANSMISSION THROUGH TIMBER FLOORS

311. The following is a review of the main points which have emerged from a study of timber floors completed by the Department of Scientific and Industrial Research just before the war and previously unpublished.

METHOD OF TRANSMISSION

312. The principal elements of the timber floor are the joists, the upper membrane, which is the floor above, and the lower membrane, the ceiling of the room below.

313. The transmission of the sound is in some measure shared by the air-space and the joists. In the transmission of air-borne sound the tendency seems to be for the joists to remain rigid and largely unmoved, so that the majority of the sound travels *via* the air-space. The extent to which this takes place appears to depend on the relative flexibility of the floor and ceiling membranes; if they are very stiff, they tend to transfer the vibrations to the joists more effectively so that the whole floor is set in motion, in which case the insulation usually drops.

314. Impact sounds appear to travel in much the same way, except that as they often occur directly over joists, the whole floor then is usually set in motion.

FLOOR SURFACE TREATMENTS

315. There is no significant difference between plain-edged boarding and the tongued and grooved alternative.

316. Carpets are useful for impact sounds, but not for air-borne.

317. A screed, carried on wood-wool sheets, proved to give about 10 db. insulation for air-borne sounds, and 5 phons for impacts. The additional weight was no doubt the most useful factor, but the added absorption in the interspace, due to the exposed wood-wool, probably helped somewhat.

318. Floating floors, of boarding on battens resting on a resilient quilt, were fairly successful. If the quilt was simply stretched over the joists to carry the floating floor, then the insulation was about 5 db. for air-borne and 5 phons for impacts. This rose to about 10 db. and 10 phons respectively, if the floating floor was itself supported by boarding. Strips of quilt only underneath the battens,

or fibreboards, and rubber cubes similarly placed were all useful, but less successful than a complete quilt overlay. The floating floor should not be nailed down, or a loss of some 5 units occurs. Floating floors are quite steady without being nailed. They are illustrated in Fig. 26.

TREATMENT OF THE AIR-SPACE

319. There are two recognized treatments for the interspace, the use of an absorbent fill, or a heavy pugging.

320. The absorbent fill, by such materials as slag-wool, has a very limited effect, possibly reaching 5 db.

321. Pugging depends on its weight to be effective, and 20 lb. per sq. ft. was found to be necessary to produce useful improvements. It is more effective for impacts than air-borne sounds, giving 5 db. for the latter, and about 10 phons for the former. Its use is shown in Fig. 26.

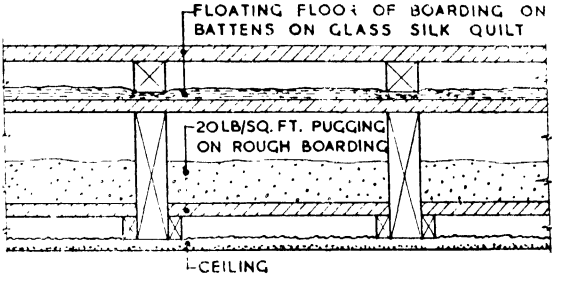


Fig. 26. THE USE OF FLOATING FINISHES AND PUGGING IN TIMBER JOIST FLOORS

TREATMENT OF THE CEILING

322. In this class of treatment tests included the case where the ceiling is carried by independent joists. It made no significant difference to the air-borne sound insulation, thus confirming that the joists take little part in transmission; however, it added about 5 phons for impact noises, as might be expected from the fact that the joists themselves are normally directly vibrated by the impacts, and that this mode of transmission is interrupted by the independent joists.

323. Comparisons were made between lath and plaster, plasterboard, and fibreboard as a ceiling membrane. The results are of some importance. The lath and plaster ceiling was, for air-borne sounds, superior to either of the others, and especially to the plasterboard by about 10 db., though the difference was not very marked for impact sounds.

324. The observations concerning plasterboard would appear to be an explanation of the deterioration in sound insulation in pre-war housing, normally attributed to the flimsiness of the construction as compared with older work. It is a particularly unfortunate deterioration where a floor of this type is used to separate two flats.

COMBINATION OF THE TREATMENTS

325. Roughly speaking the treatments are additive in their effect.

APPENDIX III
SOUND TRANSMISSION THROUGH CONCRETE FLOORS

IMPACT SOUNDS

326. The character of an impact sound on a floor depends on the nature of the exposed wearing surface and the blow which strikes it. If the bare concrete is itself exposed, and is struck or scraped by something hard, such as leather, metal, or wood, two ranges of frequencies are excited, the lower pitched flexural group based on the natural frequency of the floor as a whole, and higher pitches consisting of the waves excited within the concrete. Since in each case the vibration of the floor is the source of sound, the noise may appear as loud in the room below as in the room above.

327. The higher pitched sounds are usually considered more annoying than the others, and very considerable relief is afforded when they are suppressed. Their reduction can be effected by making either the wearing surface of the floor, or the object striking it, resilient. The architect's control extends no farther, of course, than the choice of wearing surface, but for this he can choose from a fairly wide range of usefully resilient materials, the efficiency of which has been indicated in Table VI. A more extended list can be found elsewhere.[1] Generally speaking their efficiency is limited to a reduction of about 10 phons.

328. The resilient wearing surface is not an effective insulator over the whole range of frequencies because the cushioned blow which results from an impact is favourable for the excitation of the lower pitched vibrations based on the natural frequency of the floor, and these often are found to remain troublesome. The only treatment which is known to be effective for them is the use of a floating floor, the construction of which it is the main purpose of this Appendix to describe.

FLOATING FLOORS

329. In their essentials, floating floors are rafts carrying or forming the wearing surface, and supported resiliently from the structural floor. A number have been developed in the laboratory and commercially, and have been in use successfully for a number of years. They can be inexpensive and effective. Two floating floors which have been developed in the laboratories of the National Physical Laboratory and the Building Research Station in this country are described below; for others which are patented and available commercially, standard catalogues may be consulted.

THE TIMBER FLOATING FLOOR

330. A fairly common floor finish in this country is constructed of boarding on battens fixed either in a screed on the concrete sub-floor, or in clips set in the concrete. This type of floor may be "floated" simply by resting the battens on a resilient quilt in place of the clips or screed. The most suitable quilt appears to be of glass silk, though eelgrass and slag-wool are fairly effective, as shown in Table VI. The skirting should not effect a rigid contact between floating floor and the walls (unless they themselves are insulated), and a thin resilient, such as felt or linoleum, should be inserted between them. Similarly the quilt should be

[1] Davis, A. H., and Morreau, C. J., *The Reduction of Noise in Buildings*, Building Research Special Report No. 26, pub. H.M. Stationery Office. (*Out of print.*)

turned up at the edge of the floor as illustrated in Fig. 27, to keep it from direct contact with the walls.

THE CONCRETE FLOATING FLOOR

331. The principal alternative to the board and batten floor in this country is the screed, either with a granolithic finish, or with some other suitable wearing surface applied. This floor is "floated" by pouring it *in situ* on a resilient quilt supported by the sub-floor. It has been found that a special warning is necessary concerning the process of pouring. The workmen may accidentally displace the quiltings, and thereby permit the concrete screed to flow through and set in contact with the sub-structure. All insulation is thereby destroyed. It will be a wise precaution to lap all quilt joints, and, in addition, to lay a waterproof paper to form an additional lap. The same quilts as mentioned for the timber floor have been found best for the concrete treatment as well, and where a higher degree of insulation is desired the quilt can be doubled in thickness. Skirting and edge treatments must be detailed with the precautions outlined for the timber floor, as illustrated. It is generally felt that at least a 2-in. thickness of concrete should be employed, and it is probably desirable in most cases to reinforce it with chicken wire or some similar light wire mesh.

332. Other types of floating floor have been described in other publications [1, 2], but the two given here are selected for their simplicity and economy.

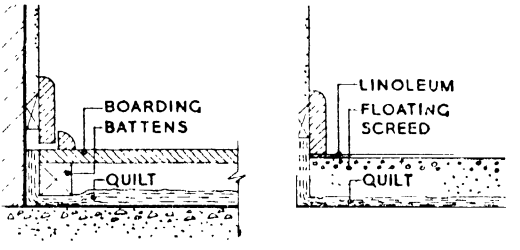


Fig. 27. FLOATING FLOORS ON CONCRETE SUB-FLOORS

AIR-BORNE SOUND

333. All reinforced concrete floors, whether or not they incorporate hollows, may be considered to act as solid homogeneous structures so far as the insulation of air-borne sound is concerned. This means that their insulation is roughly related to their weight per sq. ft. in the manner indicated elsewhere in this Report.

334. The floating floors have not yet been specifically examined in the laboratory with air-borne sound insulation in mind, but from occasional measurements which have been made, and from the experience of the comprehensive sound insulation treatments developed for flats and houses, it is known that they provide from 10 to 15 db. additional insulation.

[1] Davis, A. H., and Morreau, C. J., *The Reduction of Noise in Buildings*, Building Research Special Report No. 26, pub. H.M. Stationery Office, 1939. (*Out of print.*)

[2] Fitzmaurice, R., and Allen, W. A., *Sound Transmission in Buildings*, pub. H.M. Stationery Office, 1940. (Reprinted, 1944.)

APPENDIX IV
THE GRAPHICAL ANALYSIS OF REFLECTION IN AUDITORIA

335. Sound travels outward from a point source in a generally spherical wave front. When it meets the boundary surfaces of the room, each part of the wave is reflected at an angle equal to the angle of incidence, ultimately dispersing itself in a very complex manner. Ideally, this dispersal should be examined in some way which will show how the whole distribution takes place, but this is inconvenient, and for all practical purposes it is easier and sufficient to make a graphical analysis in plan and section separately. The method normally used may be described step by step as follows.

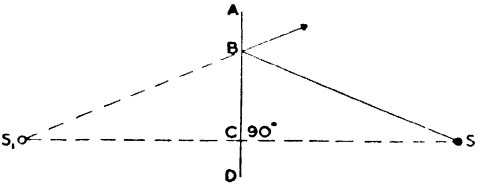


Fig. 28. REFLECTION OF A RAY OF SOUND

REFLECTION FROM A PLANE SURFACE

336. Consider a reflecting surface A B C D, and a source of sound S (Fig. 28). If sound is reflected at an angle equal to the angle of incidence, then a "ray" of sound travelling from S to B will be reflected as if it had emanated from an image of the source, at S_1, located equidistant from the plane A B C D and on a line normal to the plane at C. Then B K represents the line of the reflected ray, and the angle at which B K leaves the plane A B C D can, by simple geometry, be proved equal to the angle at which S B strikes it.

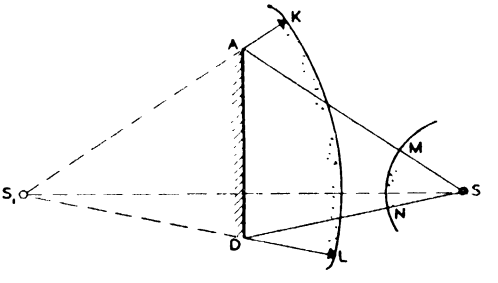


Fig. 29. REFLECTION FROM A FLAT SURFACE

337. Supposing, now, that a wave front is emanating from S, as shown in Fig. 29. Then the part of this wave which will be reflected from the whole plane shown as A D will be defined by S A and S D, and is marked M N. By the reasoning outlined above it will be seen that all the "rays" which can be assumed to make up N M will be reflected from A D as if they emanated from S_1, the image of the original source S, the reflected wave front can then be set out directly as the arc K L of a circle whose centre is at S_1.

GRAPHICAL ANALYSIS OF REFLECTION IN AUDITORIA

REFLECTION FROM A CONVEX SURFACE

338. The form of wave front which is produced as a reflection from a convex surface may be determined graphically by considering a number of individual "rays" of sound.

339. Assume a convex surface A B and a source of sound S (Fig. 30). A "ray" of sound from S meets A B at C. The image of S_1 from which the reflected ray will appear to come can be found by projecting the tangent to the reflector at C, and then drawing S D S_1 at right angles to the tangent, so that S D = S_1 D. Then C K, the reflected ray, can be drawn as a continuation of S_1 C. In a similar way the paths of a number of other rays can be determined with image sources at S_2, S_3, and so on. Then the wave front will lie along a series of points, L K M, such that the length of the path traversed by sound from S to each point is equal *i.e.* S E L = S C K = S F M.

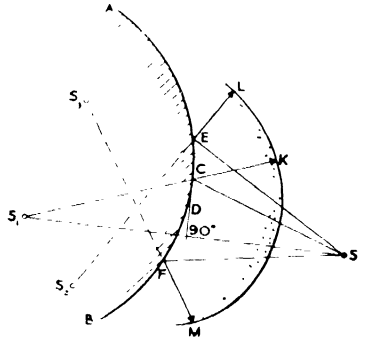


Fig. 30. REFLECTION FROM A CONVEX SURFACE

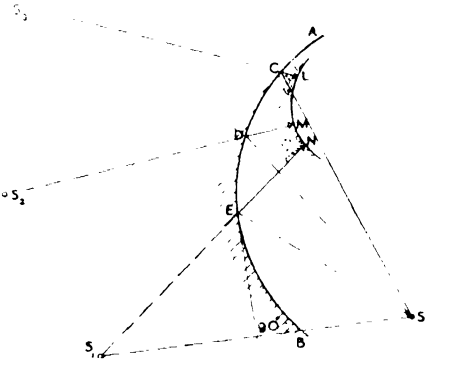


Fig. 31. REFLECTION FROM A CONCAVE SURFACE

REFLECTION FROM A CONCAVE SURFACE

340. The reflected wave front from a concave surface is determined in the same manner as for the convex surface. Considering the ray of sound from S to E, the line of reflected sound can be determined by fixing the apparent source images S_1, S_2, S_3, as before (Fig. 31). These then represent respectively the images for the three "rays" indicated, S E N, S D M, and S C L, each of which will be of the same total length from source S_1 or the image source, to the wave front.

AN EXAMPLE ANALYSIS

341. Analyses are made for different purposes and on these depends the choice of the reflections to be traced in any given case. In a hall of which complaints are made due to echo, it will be necessary to know first where the echo is observed, and then to determine graphically, unless it is obvious, what reflectors could cause echoes. In a new design, where reflection is intended for some specific purpose, such as reinforcement of sound under galleries, or in rear seats, the analysis is employed in determining the actual shape and position required for the reflectors if they are to function as intended. It is customary to trace the first reflection, in most cases, and occasionally the direct wave, and the second or even the third reflection may be found necessary in some circumstances, though this is unusual. It is desirable to keep in mind what time lag occurs with each wave, and to use, so far as possible, one length of path from source to the wave fronts shown; *i.e.* the wave fronts will be shown in their positions relative to one another at any given moment.

342. An example analysis is given in Fig. 32. Only first reflections are shown, and all are drawn with the path from the source of sound to the reflector and thence to each wave front, or from each image source to the wave front the same length.

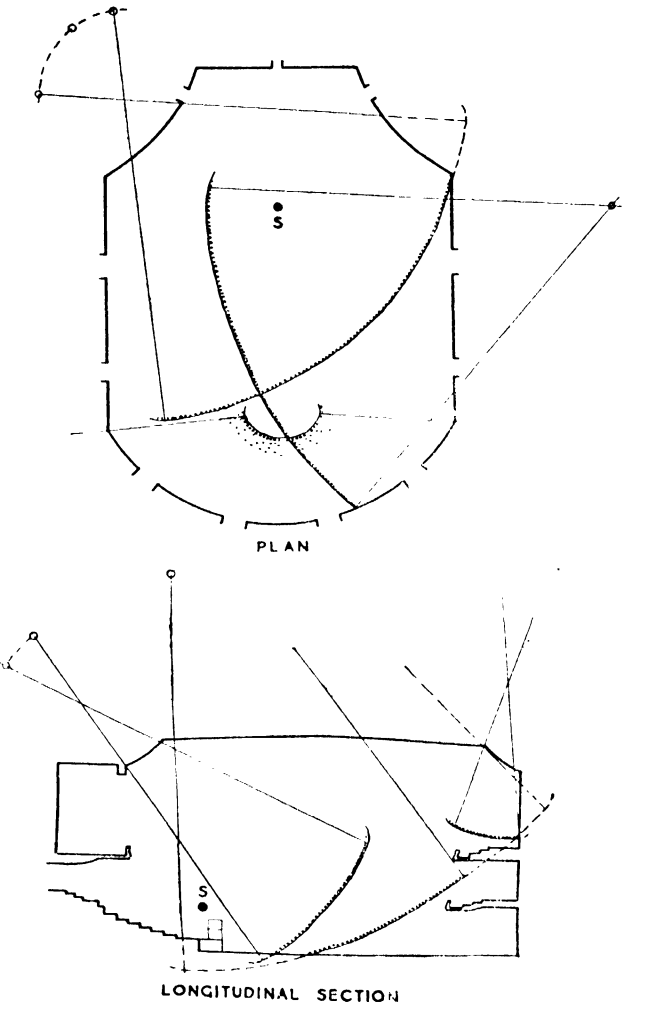


Fig. 32. AN ANALYSIS OF REFLECTIONS IN QUEEN'S HALL (Based upon the analysis by Bagenal, but showing first reflections only)

APPENDIX V
MEASUREMENT OF SOUND ABSORPTION AND SOUND INSULATION

AIR-BORNE SOUND

343. When sound is incident upon a wall surface part of the energy is reflected, part is absorbed (dissipated into heat), and part is transmitted. If sound is produced continuously in an enclosure the general sound level within the enclosure builds up, through repeated reflections, until the rate at which the energy is being absorbed and transmitted at the walls is equal to the rate at which it is being produced. If the source is then stopped, the sound dies away (reverberation) at a rate again depending on the fraction absorbed and transmitted at each reflection. This fraction is thus the important factor in determining the acoustic conditions within an enclosure, and for the purpose of auditorium acoustics the *absorption coefficient* of a surface is defined as the fraction of the incident sound energy which is absorbed and transmitted. Normally the proportion transmitted is very small compared with that absorbed. For a $4\frac{1}{2}$-in. brick wall, for instance, the proportion absorbed may be about ·03 and the proportion transmitted about 10^{-5} at medium frequencies. The only exception likely to occur in buildings is the open window.

344. The absorption coefficient of a surface varies with the frequency and with the angle of incidence of the sound. In an auditorium the sound may be incident in all directions at random, and the absorption coefficient required for auditorium calculations is that obtained under such conditions. This is termed the *reverberation absorption coefficient*. It is determined experimentally by recording with microphone and amplifier equipment, the rate of decay of sound in a reverberant room before and after the introduction of a test specimen. It is to be noted that the reverberation absorption coefficient of a material at a given frequency is not a specific constant of the material. It depends, for instance, on the thickness and on the method of mounting. Porous materials, for example, normally give greater absorption at low frequencies if the thickness is increased, or if the material is spaced away from the wall on which it is mounted.

345. The product of the absorption coefficient and the area of a surface is termed the *absorption of the surface*, and the sum of all such products in an auditorium is the total absorption of the auditorium. In the case of individual objects, such as pieces of furniture or persons, where the absorption coefficient may vary from point to point of the surface, it is only feasible to deal with the total absorption of the object. It is to be noted that the absorption coefficient is a pure number but the total absorption has dimensions $(\text{length})^2$, so that its value depends on the unit of length employed. In this country and the U.S.A. the foot is used, and the absorption is quoted in "square foot units" or "sabins."

346. The fraction of the incident sound energy which is transmitted through a partition is called the *transmission coefficient*. This also varies with the frequency and with the angle of incidence of the sound, and in practice the coefficient for sound incident in all directions at random (the *reverberation transmission coefficient*) is usually employed. For ordinary building partitions the reverberation transmission coefficient defined in this way varies over a range of more than 10^{-1} to 10^{-8}. It therefore becomes convenient to use a logarithmic scale to define the sound reduction factor of such a partition, and the units employed are decibels.[1]

Mathematically this may be stated, sound reduction factor (in decibels)

$$= 10 \log_{10} \frac{1}{\text{transmission coefficient}}.$$

This method of treatment is also advantageous in that the effect of sound on the ear is more nearly proportional to the logarithm of the sound intensity than to its absolute value. Thus transmission coefficients of from 10^{-1} to 10^{-8} correspond to sound reduction factors of from 10 to 80 decibels.

347. For the laboratory measurement of sound reduction factors the partition in question is built into an aperture between two otherwise completely isolated rooms. Reverberant sound is set up in one room, and the sound reduction factor is determined from microphone measurements of the average sound intensities in the source room and the receiving room, both with and without the partition in the aperture.

IMPACT SOUND

348. The assessment of the relative value of floor treatments in reducing the noise produced in the room below by impacts on the floor, such as footfalls, requires a different method of approach. This arises from the fact that the impact cannot be split up into a number of frequencies which can be dealt with separately. The effect of the total must therefore be measured and a standard blow, similar in energy to that of an average footfall, has to be adopted. The noise produced by this in the room below is the significant factor. This noise is measured in loudness units (phons), and the improvement of any floor treatment is evaluated by comparing the noise produced in the lower room by impacts on the treated floor, with that produced by the same impacts on the untreated basic floor.

APPENDIX VI
THE REDUCTION OF NOISE THROUGH OPEN WINDOWS

349. If a source in a room emits sound energy at a constant rate E, and the total absorption is A, then the average energy density I produced in the room when a steady condition is reached is given by $I=\frac{4E}{CA}$ where C is the velocity of sound. If the source is an open window, the difficulty is to decide what value to give to E. Probably the best approximation to the average case would be obtained by assuming reverberant sound outside. If the energy density outside is reverberant, with energy density I_1, then $E=\frac{I_1 S}{4}$, where S=area of window.

This gives $\frac{I}{I_1}=\frac{S}{A}$ where A includes the absorption due to the open window.

Then the difference in db. between sound outside is $10 \log_{10} \frac{A}{S}$.

Example I

Office, 15 ft. square and 10 ft. high, upholstered furniture and a carpet. Total absorption 75 units.

With windows open 20 sq. ft., reduction = 6 db.
" " 5 " " = 12 db.
" " 1 " " = 19 db.

Example II

Office, 15 ft. square, 10 ft. high, hard furniture, no carpet. Total absorption 30 units.

With windows open 20 sq. ft., reduction = 3 db.
" " 5 " " = 8 db.
" " 1 " " = 15 db.

Example III

Living room 12 by 15 ft. by 8 ft. high, upholstered furniture and carpet. Total absorption 50 units.

With windows open 20 sq. ft., reduction = 5 db.
" " 5 " " = 10 db.
" " 1 " " = 16 db.

350. Examples I and II show offices of normal size, one furnished with a proportion of soft materials, and the other with hard furniture and a hard floor covering. The improvement caused by the greater absorption in the first case is useful, 3 or 4 db. gain over Example II for any given size of opening, but quite obviously the size of the opening is the dominant factor. With quite a large opening, from 15 to 20 sq. ft., it will be seen that reduction of the order of 5 db. could reasonably be expected. This is, perhaps, an excessive size of opening for which to allow in design, and 5 sq. ft. might be a more reasonable figure to take, in which case a reduction of the order of 8 to 12 db. could be expected.

351. If the room is a very large room and well furnished, *e.g.* a boardroom, values of 15 db. or higher could be assumed.

BIBLIOGRAPHY

SOUND INSULATION

General Principles

Bagenal, H., *Practical Acoustics and Planning Against Noise*, pub. Methuen, 1941.
Davis, A. H., and Morreau, C. J., *The Reduction of Noise in Buildings*, Building Research Special Report No. 26, pub. H.M. Stationery Office. (*Out of print.*)
Davis, A. H., *Noise*, pub. Watts & Co., 1937.
Fitzmaurice, R., and Allen, W. A., *Sound Transmission in Buildings*, pub. H.M. Stationery Office, 1940.

Specialized Researches

Constable, J. E. R., "The Transmission of Sound in a Building by Indirect Paths," *Proceedings of the Physical Society*, 1938, Vol. 50, p. 368.
Constable, J. E. R., "The Transmission of Sound Between Neighbouring Rooms in a Brick Building," *Proceedings of the Physical Society*, 1938, Vol. 51, p. 53.
Constable, J. E. R., "The Effect of an Acoustically Absorbent Lining upon the Sound Insulating Value of a Double Partition," *Proceedings of the Physical Society*, 1937, Vol. 48, p. 690.
Constable, J. E. R., and Aston, G. H., "The Sound Insulation of Single and Complex Partitions," *The Philosophical Magazine*, January 1937, p. 161.
Constable, J. E. R., "The Sound Insulation of Double Partitions of Dissimilar Components," *The Philosophical Magazine*, August 1938, p. 253.
Constable, J. E. R., "Reduction of Noise Transmitted Along Water Pipes," *Engineering*, 1937, Vol. 144, p. 612.
Constable, J. E. R., "The Prevention of Transmission of Sound Along Water Pipes," *Proceedings of the Physical Society*, 1938, Vol. 50, p. 360.
Davis, A. H., and Knowler, A. E., "The Effect of Air Coupling in Acoustical Insulation by Means of Elastic Supports," *The Philosophical Magazine*, January 1937, p. 152.
Kawashima, S., "Transmission through Non-Porous Materials," *Journal of the Acoustical Society of America*, July 1940, p. 75, and January 1941, p. 327.
Knowler, A. E., "Space Attenuation of Impact Sounds in a Brick Building," *The Philosophical Magazine*, May 1941, p. 240.
Lindahl, R., and Sabine, P. E., "Impact Sound Transmission through Floors," *Journal of the Acoustical Society of America*, April 1940, p. 401.
Sabine, H. J., "Absorption of Noise in Ducts," *Journal of the Acoustical Society of America*, July 1940, p. 53.
Building Research Station Information Notes, Series 4, No. 2, 1939, *The Design of Concrete Floors to Reduce the Transmission of Sound.*

ACOUSTICS

General Principles

Bagenal, H., *Practical Acoustics and Planning Against Noise*, pub. Methuen, 1941.
Bagenal, H., and Wood, A., *Planning for Good Acoustics*, pub. Methuen, 1931.
Davis, A. H., *Modern Acoustics*, pub. Bell, 1934.
Knudsen, V. O., *Architectural Acoustics*, pub. Wiley & Sons, 1932.
Sabine, P. E., *Acoustics and Architecture*, pub. McGraw-Hill, 1932.

BIBLIOGRAPHY

SPECIALIZED RESEARCHES

Bagenal, H., "Cinema Acoustics," *Journal of the Royal Institute of British Architects*, 1939, Vol. 46, p. 500.

Fürrer, W., "Acoustics of Radio Studios," *Schweizer Archiv für Angewandte Wissenschaft und Technik*, 1942, No. 3, p. 77, No. 4, p. 99, and No. 5, p. 143.

MacNair, W. A., "Optimum Reverberation Times," *Journal of the Acoustical Society of America*, 1930, Vol. 1, p. 242.

Potwin, C. C., and Masefield, J. P., "Planning Acoustics," *Journal of the Acoustical Society of America*, 1938 and 1940.

"Acoustic Materials and Forms in Decoration," *Architectural Review*, April and May 1938.

SOUND ABSORPTION BY NON-POROUS MATERIALS CAPABLE OF VIBRATION

Constable, K. M., *Architect and Building News*, October 16th, 1936.

Lauffer, H., *Hochfrequency technik und Elektroacoustic*, January 1937.

Meyer, E., *Elektrische Nachrichten Technik*, March 1936.

Meyer, E., *Journal of the Acoustical Society of America*, January 1937.

(The titles of the above individual references are closely similar.)

ABSORPTION COEFFICIENTS

Letter circular No. L.C. 632, National Bureau of Standards, 1941, (U.S.A.).

Acoustical Materials Association of America, Annual Bulletins.

(The above list is in no sense exhaustive.)

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Mr. J. Wilson was originally appointed to the Committee. On his retirement from the Department of Health for Scotland Mr. Wilson's place on the Committee was taken by Mr. G. D. Macniven.

TERMS OF REFERENCE

I. To review existing scientific information and practice in this country and abroad on the acoustics and sound insulation of buildings.

II. To make recommendations for practice in post-war buildings.

III. To make such recommendations for further research as may suggest themselves in considering (I) and (II).

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NO. 15

WALLS, FLOORS AND ROOFS

BY

A COMMITTEE CONVENED BY THE

ROYAL INSTITUTE OF BRITISH ARCHITECTS



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POST-WAR BUILDING STUDIES

The series of Reports being published under the title of Post-War Building Studies owes its origin to a desire expressed by professional and other institutions connected with the building and civil engineering industries to assist and support the Ministry of Works in regard to post-war plans. During the latter part of 1941 the then Minister, in order to take advantage of these offers of assistance which he was receiving from all quarters, encouraged the establishment of a series of Committees to investigate and report on the major problems which were likely to affect peace-time building. He also offered, on behalf of the Ministry, to provide the necessary staff and organization to co-ordinate the various inquiries, in such a way as to avoid duplication of effort and to secure so far as possible uniform direction and policy.

A full list of the Reports which are being issued is given on the back page of the cover.

The Committees were either appointed by a Government Department or convened by a professional institution, a research association or a trade federation, as seemed most appropriate in each case; they were so constituted as to ensure that the Reports contain the considered views of experts and others closely concerned with the subject. The Minister gratefully acknowledges the work of the Committees and the valuable assistance given both by the various convening bodies and by the individual members. The Reports are not official publications in the sense that the Government as such is responsible for or necessarily accepts the views expressed, but their contents are authoritative and cannot but be of great value to all concerned with preparations for building after the war.

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THE ROYAL INSTITUTE OF BRITISH ARCHITECTS

WALLS, FLOORS, AND ROOFS COMMITTEE

To the Right Honourable Lord Portal, D.S.O., M.V.O., Minister of Works.

MY LORD, This Committee was convened in May 1942 by the Royal Institute of British Architects at your invitation. Our study was to be part of a scheme inaugurated by Lord Reith of Stonehaven, when Minister of Works and Buildings, with the object of securing a comprehensive and co-ordinate review of building technique for the guidance of those who would be responsible for the direction and organization of building after the war.

The Committee was charged with that part of the general scheme which relates to Walls, Floors, Roofs, and Partitions, and our Terms of Reference within this study of building were: "To review existing practice in this country and abroad on the structure of walls, floors, roofs, and partitions, to houses, flats, schools, office buildings, shops, and agricultural buildings, and to make recommendations."

The Committee having met thirty-two times, and having given full consideration to the terms of reference, now has the honour to present this Report.

The recommendations are to be considered not only for the immediate post-war period, but also for general use in the future, as fulfilling a practical standard of good construction having regard to the most economic use of labour and materials.

The Committee acknowledges its indebtedness to:

a. The officers of the Building Research Station who have supplied information which has not been published previously, and have carried out research on some of the problems with which the Committee has been concerned.

b. The Building Research Group of the Free German Institute of Science and Learning which has submitted a memorandum on building practice in Central Europe.

c. The many trade organizations and individuals who have submitted memoranda on special subjects.

The terms of reference have been interpreted by the Committee as confining it to the study of present-day building practice. Except where experience gained in emergency and experimental building has suggested an improvement in traditional practice the Committee has avoided making reference to methods of construction whose use has been insufficiently established. The Committee considers that important lessons are to be learnt from war-time building practice, and has therefore included information on this matter in an Appendix, which is based upon experience in carrying out certain types of war-time building.

In some cases the Committee has found that its recommendations conflict with existing by-laws and building regulations. Whilst it is appreciated that the Model By-laws have effected an improvement in statutory regulations, it is considered that the procedure to obtain waivers from existing regulations is unnecessarily difficult, and may be the means of discouraging revisions in practice at a time when development undoubtedly will be of importance.

Any modification in building regulations or codes which is intended to increase permissible working stresses should be accompanied by a requirement making it obligatory that such work shall be designed by those properly qualified to do so.

Upon the subject of sound insulation, the Committee has attached to this Report an Appendix referring to the general principles, and has made certain recommendations in each Part. It is pointed out that this subject involves the consideration of walls, floors, partitions, and frames collectively, and that there is little or no benefit to be derived from special precautions which do not include all parts of a structure.

The Committee has been impressed by the number of very similar proprietary articles and constructional units on the market, differing only in minor aspects. In the interests of users there would appear to be advantages in some measure of standardization of these.

Upon the subject of the provision necessary for services, the Committee has reviewed *British Standard Code of Practice, B.S.* 1043–1942, and has nothing to add to it.

The Report has been divided into three parts. Part I deals with walls and partitions, Part II with floors, and Part III with roofs. Each part is presented in three main Sections. Section I examines the subject in the light of such general properties as strength and stability, weather-resistance, thermal insulation, etc. Section II considers specific requirements for various building types as they relate to the previous Section. Section III makes recommendations which emerge from the consideration in the two previous Sections, and suggests subjects for standards and research. At the end of the Report there are the two Appendices referred to previously.

Finally the Committee wishes to thank the Director of Post-War Building, Sir James West, O.B.E., F.R.I.B.A., for his guidance and for the appointment of Mr. George Fairweather, F.R.I.B.A., and Mr. A. V. Elsey, A.R.I.B.A., to assist in the preparation of the final Report.

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ABBREVIATIONS

B.R.S.	Building Research Station
B.S.I.	British Standards Institution
B.S.	British Standard
B.Th.U.	British Thermal Unit
c.p.s.	cycles per second

WALLS, FLOORS, AND ROOFS

A REPORT BY A COMMITTEE CONVENED
BY THE ROYAL INSTITUTE OF BRITISH ARCHITECTS

PART I. WALLS AND PARTITIONS

SECTION I. GENERAL PROPERTIES

STRENGTH AND STABILITY

SCOPE

1. The Committee has excluded from consideration the subjects covered by the "Steel Structures" and the "Reinforced Concrete Structures" Study Committees. This section will therefore be mainly concerned with the strength and stability of walls in "non-framed" buildings, and as panels and partitions in "framed" buildings.

SUPPORT FROM SOIL

2. The degree to which the soil may be safely compressed in the foundations of a building can vary with different systems of construction, and the nature of the soil, the bearing strength, and other factors affecting movement, should receive consideration at the outset. Unequal settlement is likely to result in greater damage to masonry and brickwork than to those systems with a degree of structural flexibility.

EQUILIBRIUM OF WALLS

3. The equilibrium of walls is normally obtained in a building by the combined effects of the following:

a. The foundations.
b. A favourable balance resulting from the combined effects of the weight and thickness of the wall and of the forces and loadings which may be imposed.
c. The restraint that may be provided by the floors and roof.
d. The restraint that may be provided by cross walls, buttresses, etc.
e. The edge restraint that may be provided by a framework.

The degree to which these conditions are separately responsible or effective in producing equilibrium may vary considerably with different systems of construction. Attention is directed to the following comments with a view to effecting improvements.

FOUNDATIONS

4. The rule-of-thumb methods normally used to determine the width of foundations for domestic buildings take little account of the actual loadings, and are inclined to result in unequal distribution of pressure on the soil supporting different walls of the same building.

RESTRAINT FROM FLOORS AND ROOFS

5. The degree of restraint that different floor and roof structures provide may vary considerably, and there can be little doubt that present methods of design take insufficient account of this factor. The horizontal plane of restraint is also of considerable importance in the storey height intervals of buildings constructed of a light framework.

RESTRAINT FROM CROSS WALLS AND BUTTRESSES

6. The restraint and rigidity arising from cross walls are important factors in connection with the stability of a wall, but their effect on strength and stiffness is largely indeterminate. The matter requires investigation to determine accurately the effect of such restraint.

EDGE RESTRAINT OF WALLS AND PARTITIONS

7. Where walls have little, or no, function to fulfil in the load-bearing system of a building, as in panel walls to a framed structure, the restraint required for their own stability will be chiefly a matter of resistance to wind pressure, and, in the case of warehouses, to lateral pressure from the interior resulting from the storage of goods. This restraint will depend on friction and the tenacity of the jointing mortar and should be checked by calculations in special cases, especially those of exposure to high winds.

OPENINGS

8. The effect of openings on the stability of walls, particularly in walls which are assemblies of units and not monolithic, is complex, and is influenced by a variety of considerations. In the case of a single doorway with good abutments there is usually little difficulty, but where there is a range of window openings separated by areas of wall which become piers in effect, some form of framework or other reinforcement round the openings may be necessary, especially if they be unequally spaced or large. The slenderness ratio of the separating piers also becomes important, and a continuous stiffening over the heads of the openings may be required to resist racking.

EXPANSION AND CONTRACTION

9. Expansion and contraction of the materials of a wall under the varying influences of the weather or other conditions, may cause cracking and affect the stability of the structure. These factors cannot be considered without taking into consideration the interaction of all parts of the structure, as similar movements, or restraints, of parts other than the walls may aggravate the trouble. Thermal movements in roof structures may also give rise to similar difficulties. Generally, with permanent materials, the effects of expansion and contraction can be ignored in lengths of walls of less than 100 feet.

MOISTURE MOVEMENT

10. The effect of change of moisture content on the expansion and contraction of traditional walling materials is, as a rule, slight after the initial drying out has taken place. In the case of certain susceptible materials, such as concrete and some sand-lime (*B.S.* 187–1942) bricks, provision has to be made for this movement.

METHOD OF DESIGN

11. Although scientific methods of design are not practicable for walls, some useful improvements could be achieved by revision of the methods now in general use. At present the design of walls is closely regulated in the by-laws, and in some cases the Committee has found it necessary to make recommendations at variance with existing regulations.

12. The regulations relating to the use of timber gave no information about the conditions that have to be fulfilled in walls beyond stating that reasonable strength, durability, fire resistance, and weather resistance should be obtained. This treatment of the subject is inadequate, and regulations are required to govern such obvious conditions as restraint, jointing, permissible stress, and fire-stopping.

13. The by-laws adopt a useful principle when they regulate the design of steel and reinforced concrete frames by reference to approved codes, specifications, and reports. The Committee considers, however, that the information laid down in by-laws is unevenly apportioned to the various aspects of building construction, and that while steel and reinforced concrete framed construction is adequately dealt with by reference to Codes of Practice, timber, brickwork, and masonry should be investigated to determine whether they cannot be so treated. In this connection, the Committee recommends that existing regulations for loads on structures and permissible stresses allowable in the various structural materials should be reconsidered, and it is thought that such regulations are at present frequently uneconomic. Such a reconsideration of the loads and stresses, while leading to economy in the use of materials, will tend to lessen the margins of strength available to meet contingencies from accidental overloads, errors of design, indifferent workmanship, and quality of materials, and in consequence the Committee is strongly of opinion that all buildings and other structures should be designed and supervised by properly qualified persons. The tendency of allowing margins of safety in by-laws and regulations in order to cover for the contingency of indifferent structural design should give way to more scientific methods.

EXTERNAL WALLS

14. In the construction of solid walls important factors are the character of the walling materials, the nature of the bond, and the composition of the mortar. Walling materials are dealt with in *Post-War Building Study* No. 18 (*The Architectural Use of Building Materials*). The durability of a wall over a long period of years depends to an extent on the efficiency of the bond. Face bond, being visible, is usually satisfactory, but cross bond or bond in the thickness of the wall is often defective. In the case of masonry there is frequently an insufficient number of bonders, and in brickwork an improper use of bats instead of headers. A building with badly bonded walls may give little trouble in the early part of its life, but small settlements or slight movements of arches or lintels may result in unequal or increased stresses.

15. In the case of mortar, too much consideration is frequently given to the question of strength and not enough to questions of elasticity and freedom from excessive shrinkage. In the classes of buildings that are the subject of this Report it will rarely be necessary to use a very strong mortar. In brick-built buildings from three to five storeys in height, with load-bearing walls, where a cement mortar may be thought necessary, a lean mix not exceeding 1 of cement to $3\frac{1}{2}$ of sand will be generally satisfactory. In buildings not exceeding three storeys a cement mortar is undesirable; a cement-lime mix such as 1 : 2 : 9 or 1 : 3 : 9 will be sufficient. Joints formed of this material will have enough elasticity to adjust themselves to slight movements, due either to small foundation settlements or to temperature changes. This mortar will not be so much affected by shrinkage, and will in consequence have a better hold on the bricks; there will be less risk of the formation of small cracks between the mortar and the bricks, and the walling will be more weather-resisting. In districts where a good medium hydraulic lime is obtainable, this, mixed in the proportions of 1 : $2\frac{1}{2}$ or 1 : $3\frac{1}{2}$, according to the character of the sand, will also make a satisfactory mortar for ordinary use. It should be noted that the lime to be used in a cement-lime mortar is a fat lime; hydraulic limes when gauged with cement have not proved satisfactory.

16. In mortar for masonry and concrete block walling the same considerations of elasticity and relative freedom from shrinkage apply. Except in the case of granite where a cement mortar is customary, a cement-lime mortar or a lias lime mortar will be suitable in the case of the harder stones, and with soft stones a lime mortar is desirable. In concrete block walling the use of a weak and relatively elastic mortar is most necessary, as such walling is subject to moisture and temperature movements.

17. The strength of the 11-in. cavity brick wall is little more than the strength of the inner $4\frac{1}{2}$-in. thick leaf, but it is felt that this type of wall is strong enough to withstand the stresses normally encountered in the average two-storey building. On the other hand, the wall may be partly dependent for its stability on a sufficient number of ties between the two leaves of the wall. This suggests that the ties, while having a certain flexibility, should be rigid enough to ensure the stability of the wall as a whole.

18. When cavity walls are built as panels in framed multi-storeyed buildings, the stability of the walling is to some extent dependent on the number of ties between the two skins and on the fixing of the window frames. This problem of stability of the walling is statically indeterminate especially where windows occur. Experience has shown that cavity walls in panels 14 feet square built of two $4\frac{1}{2}$-in. skins of brickwork, or of an outer skin of $4\frac{1}{2}$-in. brick and an inner skin of hollow clay blocks, or solid partition blocks, have proved satisfactory in conditions of normal exposure.

19. It is important to tie the outer skin to the inner skin either just above or below the first-floor joists.

20. The practice of supporting brick courses over openings on the timber framework of the doors and windows is not recommended.

21. Hollow clay, precast concrete, and other forms of block are generally satisfactory, even when used for load-bearing purposes in the inner leaf of a cavity wall, and it is understood that a British Standard for hollow clay and similar partition blocks is being prepared.

22. The structural sufficiency of hollow block walling using blocks of lower strength must be carefully considered in regard to the bearing of lintels, and of the upper floor joists and roof members. Where the substance of the block is substantial, these items present no great difficulty, but in the open cellular type of block "specials" may be necessary to form bearings, or else recourse must be had to weak concrete filling.

23. Reinforced brickwork has been used during the war, but the Committee feels that further research on the subject is needed before recommendations can be made.

24. Mass concrete, from which the fine aggregate is omitted (no-fines), has been used as a form of construction for load-bearing external and party walls, partitions and chimney breasts, with the external surfaces rendered.

25. Tests have been made by the B.R.S. on no-fines concrete, and the following points emerged:

a. The compressive strength of 8-in. walls of the recommended mixes is sufficient for two-storey houses. The tensile and shear strength is low, so that no-fines concrete should not be subjected to unusual eccentric loads, such as might occur under the bearing of heavy lintels, and slender piers should be avoided.

b. The bond strength is low, but experience has shown that it is sufficient to justify the inclusion of some measure of reinforcement above and below openings.

WALLS BELOW GROUND

(See also paragraph 57 *et seq.*)

26. The structural design of walls below ground may be carried out in a variety of ways. These may range from simple gravity construction in which the weight of the wall and its vertical load is capable of resisting the lateral thrust, to a reinforced concrete wall either cantilevering from its foot, or designed as an apron supported by other members. The factors affecting the strength of retaining walls have not been considered, as this subject was felt to be outside the Committee's terms of reference.

27. All deflections and settlements should be kept within small limits in retaining walls. This is especially necessary in the case where there is hydrostatic pressure, or the walls are on a street frontage. It may also be necessary to pay regard to the varying conditions of stress, and consequent deformations to which a retaining wall may be subject in the different stages of its construction.

28. In the case of a retaining wall of the cantilever type, it is necessary to guard against the sliding of the wall, particularly during construction.

29. For important works below ground, in the early stages of design, an analysis should be made of the soil water (particularly in clayey soils) in order to guard against sulphates which may attack concrete or mortar in which Portland cement has been used. The attack depends on the nature and strength of the sulphate inclusions and expert advice should be sought on this point. If injurious solutions are present, means should be taken to prevent access of the water to the cement, or a luminous cement should be used.

INTERNAL WALLS AND PARTITIONS

30. For internal walls, the requirements for strength are similar to those for external walls.

31. For non-load-bearing partitions it is considered that these are often too thin, and are unable to resist stresses due to vibration and other causes without cracking.

32. It is suggested that partition design should probably be based on transverse strength, and that existing information on this subject needs to be codified. It is suggested that the Code of Practice Committee on Walls should be asked to formulate a rational design method for stability of slab and block partitions.

33. It should be noted that certain suggestions made under "Sound Insulation" for the separation of partitions from walls, floors, and roofs, may affect the stability of the partition adversely.

34. The principal defect in partitions is that of cracking, which it is not possible to prevent completely. This may be due to one or more of the following causes:

a. Defects in materials.
b. Shrinkage of one or more of the materials.
c. Deflection of the floor carrying the partition.
d. Deflection of the floor above.
e. Unequal settling of the foundations of the building.
f. In the case of partitions in the top storey of a building having a flat roof, thermal movement of the roof slab.

35. As regards (a), unsuitable mortar can cause cracking. It is suggested that cement mortar is unsuitable, and that cement-lime-sand mortar should be used. This is recommended for external walls also. (See paragraph 15.)

36. As regards (b), slab partitions composed of "fired" materials such as clay or terra cotta shrink much less than those composed of moulded materials such as concrete, as the shrinkage is limited to the jointing materials. Where cement containing material is used, care should be taken to ensure that the slabs or blocks have been allowed to dry out before being used. It should be noted that there are two *B.S.*, No. 492–1933 and No. 728–1937, dealing with precast concrete partition slabs (solid and hollow).

37. As regards (c) and (d), the deflections of the floors above and below the partition tend to produce a distortion of the rectangle filled by the partition; the latter, normally a thin brittle structure, consequently cracks, usually in a diagonal direction. Cracks are not so likely to occur in partitions erected in a completed building.

38. The risk of the cracking of a partition owing to the deflection of the floor above can be avoided by stopping the partition below such a floor, and covering the angle between the top of the partition and the floor above with a fillet fixed to the floor above only.

39. It seems that there are no means, with normal materials, of avoiding the cracking of a partition when the floor on which it rests is deflected after the partition has been erected. The main structure should be designed to minimize the floor deflection. The achievement of this objective is assisted by:

i. The avoidance of long span shallow beams.

ii. In the case of framed buildings where partitions are likely to be erected on the floor slabs and not on the beams, it is desirable that provision be made in the design of the slabs to distribute the partition loading.

iii. The reinforcement of floor slabs in both directions.

iv. The partition construction should be free to move.

With regard to (iv), the partitions should not be bonded at the ends into adjoining walls, columns, or floors, but should instead be separated from them by felt strips, the angles being covered with fillets fixed to the walls, columns, or floors.

40. As already noted, this separation of the partition from the main structure tends to reduce the stability of the partition and remove any stiffening effect the partition may have to the external or cross wall. Allowance should be made for this.

41. As regards (e), it should be noted that distortion of the rectangle filled by the partition may be due also to unequal foundation settlement resulting from differential loading. It is believed that modern studies of soil mechanics will throw some interesting light on this and other related problems.

42. As regards (f), it is desirable to stop the partition below the under side of the roof slab, pack the gap with felt, and cover the angle with a fillet or cove attached to the roof slab.

43. The provision and fixing of electrical and other services should be borne in mind when deciding upon the materials of which partitions are to be constructed. Chases for the accommodation of the services can be cut in brick, breeze block, and concrete block partitions, but such chases weaken a thin partition.

44. Partitions are often required to support lavatory basins, w.c. waste preventers, shelves, etc.; 4½-in. brickwork with fixings built-in is a suitable structure for this, but for light partitions such as hollow clay block, breeze block, and pumice block, additional means may be necessary to provide support.

RESISTANCE TO WEATHER AND DAMPNESS

RAINFALL

45. As the intensity and volume of rainfall vary considerably in different parts of the British Isles, walls which will resist rain penetration in one area may be unsuitable in another. Local inquiries should be made.

WIND

46. The aspect of a wall in relation to the prevailing wind has an important effect on its resistance to rain. While the wall facing the prevailing wind is liable to be persistently damp, it has to be recognized that at some season or other exceptionally prolonged rain may be driven from some other quarter and there may be temporary dampness on other faces.

PROPERTIES OF WALLS AS THEY AFFECT WEATHER RESISTANCE

47. Most of the normal walling materials - brick, stone, many concretes, etc.— have a porous structure and absorb rainwater which falls on them to a greater or less extent. If the rain persists for a sufficient length of time the walls will become saturated and damp patches will appear at the inner face. If, however, the locality is such that rainfall is not persistent for long periods, a highly absorbent brick or stone may absorb rain during a wet period without reaching saturation. The wall will lose the water by evaporation to the outer air in fine weather and the inner face will remain dry. With walls built of dense and relatively non-absorbent units, however, rain falling on the walls, streams down the outer face and turns into the body of the wall at any crack or fissure and very soon reaches the inner face. There is thus the anomaly that the denser or less absorptive unit may give the wetter wall, because there is no reservoir of porous material to hold up the rain.

48. The practical conclusion reached by the Committee is that walls built of fine-pored, absorptive units can be relied upon to hold back the weather, in sheltered positions where the local rainfall is moderate, without any special demand on workmanship. Dense, non-absorptive units, on the other hand, can only be successful when the mortar joints are fully filled and of the same order of impermeability as the walling units, and when the jointing is carried out with a perfection of workmanship which calls for closer supervision.

EFFECTS OF POOR WEATHER RESISTANCE

DURABILITY

49. Unfavourable reactions occur by the movement of soluble salts, and these sometimes cause discoloration of the surfaces or disintegration of the materials. Excessively damp conditions promote the growth of fungus or mould and cause decay of timber and corrosion of metal. Pollution by acid gases may cause similar conditions in walling materials which have inferior resistance.

DISCOLORATION

50. Local discoloration on walls due to infiltration or concentration of surface water often results in a patchy and unsatisfactory appearance, and in a bad case may result in premature deterioration of masonry or brickwork by the movement of soluble salts carried by the water. Traditional details on weatherings, sills, hoods, cornices, and strings had their utilitarian as well as their ornamental value, and their omission brings difficulties in its train which the wider use of metal or asphalt weatherings on all horizontal surfaces would go far towards avoiding. The function of the weathering is to prevent the entry of water at the horizontal surface and to discharge it clear of the wall face in such a way as to avoid a concentrated drip at a few points. This subject is dealt with in *The Journal of the Royal Institute of British Architects*, Volume 47, Third Series, pages 57 to 61, 15th January 1940.

EXTERNAL WALLS

51. Cavity walls are reliable for the exclusion of weather if they are carefully designed and built. Failure to resist damp can usually be traced to bad detailing at parapets, sills, heads and jambs of openings, and at damp courses; or to careless workmanship generally, and in neglecting to keep the cavity clear and the ties free from mortar droppings. Precautions taken to prevent the passage of water from the outer to the inner skin should include the following:

a. The use of wall ties which will either trap or throw off the water.

b. The provision of open vertical joints to allow the escape of water at points where it is likely to collect, as it does over openings.

c. The prevention of mortar droppings from entering the cavity during construction by means of a movable board or sacking, and the cleaning out of the foot of the cavity on completion through openings which have been left and filled temporarily with bricks in sand.

d. Carrying the cavity down to at least two courses below the damp course, so as to provide a space into which any mortar droppings which have escaped notice during building, or fall after completion, can collect without forming a bridge across the cavity above damp course.

e. The provision of damp courses over openings.

f. The provision for vertical damp courses or cavities at the jambs of openings.

52. In order to keep the cavity free from mortar droppings the accepted standard of 2 in. must be regarded as a minimum. Considerations which favour a somewhat wider space are that if it were increased, the jambs, in which a vertical course of slates in gauged mortar is provided as a damp course, could be constructed with purpose-made three-quarter bricks. The extra width would facilitate cleaning out the cavity during construction.

53. As a variant on the normal brick wall, the Committee has noted that new forms of hollow burnt clay walling blocks have recently become available and these may be found to offer important advantages. The characteristics of the blocks which commend themselves are a design of the bedding joint with interlocking tongues and grooves so that penetration of rain is checked. The tongues also provide a convenient hand-hold for the bricklayer, so that the blocks can be placed in position with one hand. This provides a rapidly erected, single thickness, cellular wall which, with proper workmanship, can be relied upon to exclude rain under most conditions. Such walls can be finished externally in rendering, roughcast or pebble dash, but the same considerations apply as when these finishes are used on brickwork.

54. Thirteen-and-half-inch solid brickwork is necessary for load-bearing walls of buildings up to four or five storeys in height, and these walls may serve to exclude rain, even when unrendered. Nevertheless, there is doubt as to the reliability of solid walls of this thickness in giving dry conditions in exposed situations, especially when the standard of heating in the buildings is low.

WATERPROOF COVERINGS

55. The use of thin, waterproof coverings to solid walls is a method of getting a rain-resisting wall, and these usually consist of brush-applied coatings of oils or bitumen, or thin rendered coatings. The Committee is impressed by the disappointing results which are sometimes obtained by both types of covering. The mechanism of penetration is similar to the effect described in paragraph 47 preceding. Rain streams down the impervious surface but turns in at any crack or fissure, and soaks into the wall behind the coverings. When fine weather follows

rain, however, the covering prevents the evaporation of the water content. Here again we have an anomaly in that a dense, non-absorptive coating can, in unfavourable circumstances, result in a wall being wetter than an untreated one. Clearly the practical recommendation is that the avoidance of cracks is a prior consideration for any type of waterproof coating. Brush-applied coatings will crack if cracks form in the wall to which they are applied. The prevention of crack formation is notoriously difficult with renderings, and as a general rule the more dense and impermeable they are made the greater is the likelihood of major crack formation. Highly trowelled, rendered finishes, rich in cement, must rank as the most difficult to avoid cracking. Leaner cement mixes with carefully graded aggregates give better results, and particularly so if the rich skin which comes to the surface under the trowel is scraped off. Additions of lime to cement mixes with well-chosen aggregates and, again, with scraped finishes, also give good results, and mixes of this type have been much used in Central Europe. A word of warning is necessary here. A decreasing cement content tends to give a decrease in the tendency for major crack formation, but at the expense of a measure of frost resistance. When the cement content is decreased appreciably below the lime content then there is the danger of frost failure of renderings in the north of England and in Scotland when frost follows on rain. The mixes high in lime tend to become very porous and have a useful reservoir effect (see paragraph 47), but will not suffice in localities where rainfall is persistent and exposure severe. This effect is known in European countries. Renderings based essentially on lime mixes give good results in Berlin and Vienna, but would not give waterproof walls at Hamburg or Ostend. Some general information and suggestions for mixes and technique of their application are given in *B.R.S. Bulletin* No. 16 (*External Rendered Finishes*).

56. Harmful inter-action between salts contained in the bricks and the rendered coating may occur, but very little information is available. Moreover, the composition and method of application of the coating needs to be carefully controlled. Some guidance may be obtained from the *Principles of Modern Building*, Vol. I (Fitzmaurice). The Committee notes that cracking with these coatings tends to fall into the following order:

a. Pebble dash. Cracking very infrequent.

b. Roughcast. Cracking infrequent and not often resulting in any major failure.

c. Renderings. Dense trowelled finishes tend to crack extensively and may often fail completely. (See paragraph 55.)

In the pebble dash and roughcast coating, the tendency is for a multitude of fine cracks to form round the pebbles in the pebble dash and at the many irregularities in the roughcast. In this way the formation of major cracks by which rain can penetrate freely is avoided.

WALLS BELOW GROUND

57. A basement to an ordinary dwelling house is sometimes required, and cases also arise in which, due to the slope of the ground, the lower storey of a house may have some portions of its enclosing walls built against the earth. Although it is possible to build such walls with strictly selected materials (using Portland cement mortar, in the case of brick and block walls) so that they will be resistant to damp, it is not often that the workmanship can be relied upon, and in consequence a vertical and horizontal damp course is considered the best provision. In cases where all risk of hydrostatic pressure is absent, the provision of a damp resisting rendering on the inside of the wall may suffice, but in many cases an impervious lining on the outside surface of the wall is the only reliable expedient.

58. In cases where the building of a single house, or a few houses together, would not justify the introduction of the special trade of asphalting, a lining of slates in Portland cement, Caithness stone slabs in Portland cement (Scotland), or stoneware tiles in Portland cement, applied to the external face of the wall, is reliable in the absence of hydrostatic pressure. Slates, stones, or tiles must be built to lap joint both horizontally and vertically and must be thoroughly laid in cement mortar. The junction with the horizontal damp course at the foot of the wall and the method of returning a vertical corner are details needing careful consideration.

59. In cases where hydrostatic pressure has to be resisted these provisions fall short of a completely impervious barrier. Two methods are possible in such cases; to construct the wall of scientifically graded and throughly consolidated *in situ* concrete, either mass or reinforced, or to provide a three-coat rendering of mastic asphalt, having a total thickness of not less than $1\frac{1}{8}$ in.

60. Where space is available the construction of a dry area connected with the permanent drainage system is also a sound method of dealing with the problem of dry basement construction.

61. The construction of the retaining walls forming the enclosures to the basement of a commercial building will be largely affected by the number of storeys required below ground. For single basements the use of brick walls is economically possible, but where the depth exceeds this, as in the case of two or more storeys below the ground, some form of reinforced concrete construction is desirable, and with deep basements it is often necessary to provide against hydrostatic pressure.

62. With reinforced concrete construction the problem of waterproofing may be solved in three ways: (1) by providing an impervious skin to the outside of the walling, (2) by providing an impervious skin on the inside of the wall, suitably held in place by a facing wall where necessary, or (3) by carrying out the work in water-resisting concrete.

63. The first method keeps the water out of the construction, and on this score is better in principle than the second method of stopping it at the interior surface. On the other hand faults, due to poor workmanship, or cracks arising from settlement or shrinkage movements, are practically impossible to locate and are not uncommon, whereas remedial measures are relatively simple if the impervious layer is on the inside. The third method depends for its success largely on the provision of scientifically graded concrete and its thorough consolidation.

CHOICE OF METHOD

64. Which method is employed will depend in many cases on associated conditions such as, for example, the lack of sufficient room in front of the wall, due to site restrictions, to enable asphalting to be applied to the outside of the wall itself. In consequence, the Committee considers that specific recommendations cannot be made.

ASPHALTING TO OUTSIDE OF WALL

65. If the asphalting is to be outside the wall the most reliable method is to apply the asphalt directly to it. Where possible, the excavations should be sloped back in order to obviate strutting from the wall; but where this cannot be avoided a properly thought-out system of changing the positions of the struts, in order to asphalt the patches occupied by the ends of the struts in their original positions, should be devised.

66. In this connection it is necessary to protect the asphalt as it is applied, by a lining of 4½-in. brickwork and to re-bear the struts in their changed positions, upon this protective face. In this way, damage to the asphalt is prevented. The pressure communicated to the asphalt by the struts should be limited to about 6 to 8 tons per square foot. The back filling to the wall should be deposited in shallow layers, well consolidated, and in cases where the filling would be of such a nature as to permit the accumulation of surface water a back fill of concrete may be warranted, or where drainage can be arranged, the provision of a rubble drain near the base of the wall. It is important that the horizontal asphalt be carried a sufficient distance beyond the face of the vertical work to enable a proper junction to be effected with the vertical work, so that an ample angle fillet may be formed.

ASPHALTING ON LINING

67. In some cases, the importance of obviating, as far as possible, movement of the adjacent earth and any roadways, buildings, or other structures dependent on its support, or for lack of space, it is necessary to construct a thin reinforced concrete apron or brickwork lining against the earth as the excavation proceeds, and to strut across from it. The asphalt is then applied to the surface of this apron and the patches asphalted after the struts have been shifted to new positions, as described above. In such cases, it is usual to construct the retaining wall directly against the asphalt. This constitutes a source of damage to the asphalt due to careless handling of reinforcing bars and to rodding concrete into place. In order to guard against this it is recommended that the asphalt should be protected with a facing of brickwork or concrete.

PROTECTION OF ASPHALT AGAINST FRACTURE

68. In the design and throughout the construction of retaining walls of this type where the asphalt occurs on the outside of the walling and below its foundations, attention is again directed to the importance of seeing that all deformations such as deflections and settlements arising from the stresses evoked in the wall, its foundations and other supports (if any) are kept within small limits in order to prevent fracturing of the asphalt. Right-angled corners should, as far as possible, be avoided, and changes in the level of the horizontal asphalt should be made by slopes. It is important to form angle fillets between the horizontal and vertical asphalting, and to protect the horizontal asphalting by a layer of carefully placed concrete which should be allowed to harden off one clear day before assembly of the reinforcement is begun.

WATERPROOFING TO INSIDE OF WALL

69. The alternative method of providing the asphalt layer on the inside of the structural wall will necessitate the provision of a lining to protect and hold both the horizontal and vertical asphalt. Hydrostatic pressure will be communicated through the concrete, entirely or in part, to the inner surface of the asphalt. In consequence, the protective lining and floor must be designed to withstand this pressure, and are usually constructed of reinforced concrete.

TREATMENT OF STANCHIONS

70. Difficulty arises in respect of the horizontal asphalting when this alternative method of asphalting on the inside of the structure is employed. In order to accommodate the load from internal stanchions, reinforced concrete columns or piers, a considerable spread is necessary over the asphalt in order to limit the compression on the asphalt to something of the order of 8 tons per square foot, and in cases where bases designed to limit this pressure would necessitate projections above the basement floor an alternative is sometimes considered. This alternative consists of forming a pipe of asphalt around the stanchion, column, or

pier, making junction with the horizontal asphalt and carried up to a short distance above the maximum head of water; the foundations having been formed below the level of the horizontal asphalt. This method assumes that the stanchion, reinforced concrete column or pier, is saturated either permanently or periodically with water. In the case of a stanchion, the steelwork must be encased in concrete and the asphalt applied thereto with an ample fillet formed with the horizontal asphalt, and the pipe of asphalt must be protected by a thin casing of reinforced concrete capable of resisting the full hydrostatic pressure.

71. As an alternative the stanchion bases may be bedded on sheet lead with the asphalt married to the margins of the lead around the stanchion bases. In order to obtain a reliable seal it is necessary for the lead to be carried not less than 9 in. into the asphalt—the asphalt passing under and over the lead.

72. In the case of external stanchions difficulties with asphalting are reduced if concrete piers are carried up, as part of the retaining wall, to a few feet above the height of the maximum head of water, and the stanchions placed on the top of the piers.

73. It has not been possible in the space available to deal with all the associated details on which successful "tanking" depends. The Committee calls attention to *B.S.* 1097–1943, and *Asphalt in Building Construction, Roofs and Basements* (Natural Asphalt Mine Owners' and Manufacturers' Council).

NON-ASPHALTED WALLS

74. Reliance on the water resistance of concrete to withstand heavy hydrostatic pressure is precarious. The concreting of reinforced concrete retaining walls cannot, as a rule, be done with the care necessary to produce a thoroughly dense and homogeneous concrete, owing to the difficulty of working around strutting and forming proper construction joints. The inclusion of waterproofing admixtures may serve to produce better results but cannot be regarded as reliable in the absence of a thoroughly dense and homogeneous concrete. Cases have, however, been successfully carried out in which a dense concrete is rendered on its inner surface with a waterproofed cement.

75. As an alternative to mastic asphalt, asphaltic bitumen on a fabric base gives satisfactory results if applied in three or more lapped layers ultimately sealed into place with a blow-lamp (see *B.S.* 743–1941). Inferior impregnated "papers" are useless for permanently resisting free water in contact with them, and should not be used.

PARTY AND EXTERNAL WALLS

DAMP-PROOF COURSE

76. A damp-proof course, whether used in the base of a wall to prevent moisture creeping up from below or in a parapet or chimney stack to prevent moisture penetrating downwards, must be of a durable material, having an effective life equal to that of the wall. The materials in general use are:

Slates in cement.
Highly vitreous bricks.
Caithness stone slabs (Scotland).
Hollow stoneware slabs.
Sheet lead.
Sheet copper.
Bitumen base on hessian or felt.
Asphaltic bitumen.
Lead sheet between two layers of bituminous felt.
Asphalt.

77. Sheet lead, although impervious to moisture, is liable to be affected by the action of free lime in freshly placed cement or concrete and may deteriorate badly

unless protected by a layer of felt bitumen or pitch. The form of damp-proof course composed of bitumen on a base of hessian or felt requires to be of good materials, as otherwise there is a risk that the bitumen may be pressed out by the weight of the wall in warm weather, or that the materials may deteriorate in the course of years to such an extent that they no longer prevent the penetration of damp. The thickness of lead in the compound lead-and-bitumen type is often insufficient, being little more than that of tin-foil. When forming a damp-proof course in an existing wall, there are advantages in using hollow glazed stoneware slabs, as the slabs are manufactured of wall-thickness sizes.

LEVEL OF DAMP COURSE IN WALLS

78. In solid wall construction it is usual to place the damp-proof course not less than 6 in. above the finished ground level, and also below the under side of any timber in the floor construction. This requirement governs the ground floor level in a building with an open-joist floor, the minimum height of floor level above ground level being about 13 in. with flooring, joists, and plates of normal thickness and sizes. Wherever possible this height should be increased, as there is a risk, after the completion of the building, of the ground level being raised by gardening operations.

79. In the case of a solid floor, the level of the floor should be so arranged that the damp-proof course is in the first course below the top of the surface concrete, which in normal cases forms the relatively impervious base of the floor.

DOOR AND WINDOW OPENINGS IN SOLID WALLS

80. While in sheltered positions in the south of England the risk of the penetration of moisture at the jambs of openings is not great, in the north of England, in Scotland, and in exposed positions anywhere, troubles due to moisture penetration at the jambs are very liable to occur, particularly when the frames are of poorly seasoned timber. All possible precautions should therefore be taken. It appears, however, to be very difficult to form a joint between the timber and the wall jamb which will remain entirely resistant to capillary attraction; the movement of the timber, owing to changes in moisture content, will break any ordinary joint that may be formed. The provision of an air check is therefore a suitable method. This may be obtained by forming a wide groove in the side of the frame and by pointing only the edge of the junction between the frame and the wall jamb.

81. From the standpoint of weather resistance, door and window frames are best set back at least $4\frac{1}{2}$ in. from the wall face. With this arrangement, however, there is a risk, if the walling material is porous, of moisture penetrating the reveals and reaching the inside of the wall. To prevent this the reveals may be rendered, or a space may be created between the inner jambs and the finishing material by fixing wood linings on battens, or a lath-and-plaster finish on battens.

82. Window sills should be designed to throw the rainwater clear of the wall face, and the customary metal water-bar should always be provided to seal the horizontal joint between a wood sill and the stone or brick sill on which it rests.

OPENINGS IN CAVITY WALLS

83. The check to the penetration of moisture at the jambs of openings in cavity walls depends on the form of construction adopted. If the inner leaf of the wall is not returned at the openings, but the cavity sealed only by a vertical course of slates at right angles to the wall, as is sometimes done, the cavity itself forms the moisture check. If, however, the inner leaf is returned at the openings, and in this way is brought into contact with the cavity face of the outer leaf, a vertical course of slates wider than the plane of contact must be provided to form a break in order to prevent the penetration of moisture.

84. Except in cases where specially constructed lintels of impervious reinforced concrete are provided of a width equal to the total thickness of the hollow wall, the head of an opening should always be provided with the customary deep lead apron carried across the cavity and up the face of the inner leaf, and carried through a bed joint in the outer leaf to form a drip. If, owing to the exposed position of the wall or to the porous nature of the material of the outer leaf, there is likely to be a considerable penetration of moisture through the outer leaf, open vertical joints should be left above the lead apron to facilitate the drainage of this moisture to the outer face.

WALL HEAD AND ROOF JUNCTIONS

85. The simplest and most efficient way of finishing the junction between a roof and the top of a wall is by forming an eaves. This arrangement is simple because it respects the separate requirements of the two structures where they join, and is capable of wide variation in design without prejudice to the effectiveness of its construction. The arrangement is efficient because the requirements of support may be respected without reference to conditions other than those of stability, and because the roof protects the top of the wall from the weather.

86. By forming a parapet, the wall is exposed to the weather and difficulties arise. The horizontal surface at the top of the wall is exposed to a greater concentration of rainwater than the vertical surfaces, and it is affected by the heat of the sun to a much greater degree. For this reason a coping is a practical necessity; also a damp-proof course under the coping is necessary as an added precaution; this in the case of a brick-on-edge coping is essential.

87. Exposure on the two faces of a solid parapet wall may produce unsightly discoloration and gradual disintegration of the materials. This may be avoided by protecting the back of the parapet against the weather, and although a rendering may prove useful in this way, a metal flashing or deep apron will give more certain results.

88. The parapet of a cavity-built wall should also embody a cavity. This is not always done, with the result that discoloration is a common feature in the solid parapet.

FIREPLACES AND FLUES

89. Exposure to extreme weather conditions creates special problems in the walls of fireplaces and flues. When exposed externally, these walls should therefore be at least 9 in. thick, and where possible, materials should be selected for their resistance to rain and frost action. The L.C.C. By-laws provide that the highest six courses of a brick-built chimney should be jointed with cement mortar. This should be adopted in all cases, whether or not required by by-laws. The tops of chimneys should have properly weathered flaunchings in cement mortar.

90. The need for a moisture check in the brickwork of a chimney as it passes through the roof of a building is frequently ignored. In practice, a damp-proof course is sometimes laid in the bed joint level with the highest flashings, but this does not provide a complete check against damp because it leaves an exposed area of brickwork where the roof is pitched. More effective results will generally be obtained if a horizontal damp-proof course is laid in the bed joint level with the lowest flashings. It is generally recognized that the damp-proof course should be stepped with the flashings, but this involves difficulties in execution. Where the use of different kinds of brick in the height of a chimney is admissible, an effective check to moisture penetration may be obtained by inserting courses of impervious brickwork in cement mortar through the height of the roof intersection.

THERMAL INSULATION

PRINCIPLES

91. The purposes for which the thermal insulation of a building are required may be summarized as being:

a. To prevent undue loss of heat from within a building.
b. To prevent undue gain of heat from external conditions.
c. To prevent condensation.
d. To restrict expansion and contraction of the structure.

These four purposes are not necessarily dealt with in the same manner, the provisions necessary for (d) being different from those required for the others.

92. The Committee suggests that designers who wish to become acquainted with the general principles should study the following:

The Principles of Modern Building, Vol. I (Fitzmaurice)	B.R.S.
The Computation of Heating Requirements for Buildings	Institution of Heating and Ventilating Engineers.
Questions and Answers (4th Series, No. 5)	B.R.S.
Thermal Insulation of Buildings	Ministry of Fuel and Power.
Post-War Building Study No. 19 (*Heating and Ventilation*)	

EXTERNAL CONDITIONS

93. The factors affecting losses of heat from within a building are external and internal. External conditions are:

CLIMATE

94. Climate is important as determining the probable differences between internal and external temperatures, and within the limits of Britain the climatic conditions vary sufficiently to call for more insulation in Scotland, and the north than in the south of England.

EXPOSURE

95. High winds and driving rains have an important effect on heat loss, and insulation is generally more important in the country and in high localities than in towns and low-lying localities.

ORIENTATION

96. The Heating and Ventilation Study Committee has pointed out that rooms facing south require 10 to 20 per cent less heat than rooms facing north. This indicates that insulation should ideally be varied according to aspect. It is probable that north-east/north-west/south-east/south-west orientation gives better distribution of solar heat round a building than north/south/east/west orientation. The Building Research Group of the Free German Institute of Science and Learning stress the fact that the shape of a building has a definite bearing on possible heat losses through walls, floors, and roof. For example, assuming that material and thickness of walls, floors, roofs, and windows, and all other factors

which influence heat losses are identical, then a square plan will give the smallest area of external walling for any given floor area and, therefore, the least possible area through which heat losses may occur.

97. Although these external conditions are important, and their effect indicates that each case must be considered on its merits, nevertheless it is considered that such conditions are outside the terms of reference of the Committee, and they are not considered here in detail.

INTERNAL CONDITIONS

TRANSMISSION THROUGH STRUCTURE

98. The loss of heat by transmission through the structure and its surface films is measured in terms of the thermal transmittance coefficient "U," which is the number of B.Th.U. transmitted per hour through a square foot of the construction when a temperature difference of one degree Fahrenheit exists between the air on the two sides.

99. The values of "U" recommended by the B.R.S. have been raised in recent years, and two standards are now recommended according to whether the heating appliance is controlled or not, as follows:

Standard A	*Standard B*
(Uncontrolled heating appliance being of the normal open fire type.)	(Controlled heating appliance being in the nature of the slow combustion gas or oil stove, or electric heater, or the appliance of a central-heating system.)
External walls—generally 0·30.	External walls—generally 0·20.
,, ,, living rooms 0·20.	,, ,, living rooms 0·15.

100. These "U" values are for a normal exposure such as would occur above the first two storeys in towns, and at all storey levels of most suburban and country buildings. It will be noted than these "U" values are lower (or call for higher insulation) where the heating appliance is controlled than where uncontrolled. This is because the full benefits of thermal insulation cannot be realized unless the heating appliances are fully controllable. In the case of normal open fires there is a minimum rate of burning below which the fire goes out, so that there is a likelihood of overheating in spring and autumn, and under these circumstances the amount of insulation required to save any appreciable quantity of fuel in winter would be uneconomic.

INNER SURFACES

101. In addition to transmission through the structure, the temperature of the inner surfaces is important, because in raising the temperature of a room to a comfortable extent, there is a substantial time lag whilst it is warming up and during which it is not warm enough for comfort. If this heating-up period can be reduced a saving in fuel can be made. This occurs because normally the whole fabric has to be warmed, but if it is possible to warm the inner surface of a room, and not the whole fabric, the heating-up period can be reduced. The explanation of this is that if the wall can be lined with a material having a low thermal capacity (*i.e.* a material only requiring a small amount of heat to raise its temperature) and a low conductivity (*i.e.* a material through which the heat is not quickly diffused from the surface), then the surface will warm up quickly and the heat be retained on the surface and not be dissipated into the main structure of the fabric.

MOVEMENT OF AIR

102. Considerable heat loss may occur by the movement of air through crevices round opening lights and doors. This cause of heat loss cannot be entirely eliminated but can be usefully reduced by careful attention to detail in the elimination of straight joints in these positions. The heat lost up ventilated fireplaces is substantial, but care must be taken to ensure that remedial measures will not check the natural ventilation of the room, and cause nuisances from smoke and other products of combustion. This heat loss, with uncontrolled heating appliances such as the normal open fire, can be reduced by introducing air from the outside to the hearth or other appropriate point adjoining the fireplace, by means of a pipe or vent under the floor. An air-inlet of this description should be controllable by shutter or otherwise, so that sufficient air is drawn from the room to provide a reasonable air-change.

103. It is considered that as the thermal efficiency of a cavity wall is decreased by the provision of vents (usually at the bottom and top of the cavity) they should not be provided.

RELATIVE IMPORTANCE OF VARIOUS SOURCES OF HEAT LOSS

104. The total heat requirement for a warm building is made up of the sum of the losses through walls, floors, and roofs, together with the loss through the windows, and the heat needed to raise the temperature of the incoming air required for ventilation. Owing to the low value of thermal insulation of window glass, making good the heat lost through the windows is a significant proportion of the total heat requirement of a room, and as the insulation of walls and roofs is increased the heat loss through the windows assumes relatively greater importance. With a tendency for greater areas of window the Committee concludes that attention needs to be focussed on the heat loss from them. The rate of air-change depends to some degree on the air infiltration round windows and doors, but with some forms of heating, notably open coal fires, the air-change is largely determined by the air removed by the heating appliance. It is evident that economy in fuel calls for control of ventilation as well as a rational treatment of insulation.

CONDENSATION

105. Condensation can be a serious nuisance in buildings, and arises when the wall or other surfaces are cold enough to reduce the temperature of the air in contact with them to below dew-point. It is not always possible to prevent condensation by insulation, and where this is the case, provision should be made for collecting and draining the condensation water.

PATTERN STAINING

106. Pattern staining of the surfaces is liable to occur where the materials of the structure are of unequal thermal conductivity, and is accentuated where insulation is unsuitable or inadequate. Attention is drawn to *B.R.S. Bulletin No. 10, Prevention of Pattern Staining of Plasters* (1931, H.M. Stationery Office).

STRUCTURAL MOVEMENT

107. Where the structure is not insulated against temperature change, thermal movements may have to be controlled by other means. Expansion joints should be introduced where necessary.

EXTERNAL WALLS

108. The recommended Standard A for external walls generally (0·30) can be attained by normal good construction, such as 11-in. sealed cavity brick wall plastered internally. In order to achieve Standard A for external walls to living rooms (or Standard B for external walls, generally 0·20), there are two alternatives:

a. The use of different materials or methods of construction to those normally used, without special linings, examples of which are:

5″ pumice concrete, rendered externally, plastered internally.
9″ foamed slag concrete ,, ,, ,, ,,
10″ clinker concrete ,, ,, ,, ,,
12″ no-fines concrete ,, ,, ,, ,,

or combinations of structural materials, incorporating an air-space, such as:

4½″ brickwork, 2″ air-space, and 4″ pumice concrete plastered internally.
7″ foamed slag ,, ,,
8″ clinker ,, ,,
6″ hollow clay block ,, ,,
3″ diatomaceous earth block plastered internally.
9″ brickwork 3″ pumice concrete.
5″ foamed slag.
4″ hollow clay block.
4″ hollow clay block rendered, 2″ air-space, 3″ clinker concrete slab, plastered internally.

b. The use of internal linings, with or without air-space. Using the 11-in. sealed cavity brick wall plastered internally as a standard backing, the following are examples of the linings that would be required:

¼″ fibreboard, without air-space.
⅜″ cork ,, ,,
½″ softwood panelling, with 1″ air-space.
½″ plasterboard ,, ,,

109. The recommended Standard B for external walls to living rooms (0·15) can only be attained by special forms of construction that do not come within the terms of reference of the Committee. The Committee is of the opinion that this value cannot be achieved economically by the methods and materials in general use before the war.

110. Linings of the character referred to in paragraph 108 (b) permit a more rapid heating up of the inner surfaces than would occur with the types of walls referred to in paragraph 108 (a) and show how the conditions referred to in paragraph 101 may be obtained.

111. Of the few lining materials that have been tried for this purpose, fibreboard has been found to be the best, then plywood, and then plasterboard or hardboard. Asbestos cement was found to be less effective. Except in the case of fibreboard, the value of these materials was found to be improved if there was an air-space between them and the wall, whilst their value was reduced if they were covered with normal plasters.

112. There are, however, certain drawbacks to linings incorporating an air-space, such as additional harbourage for vermin, and reduction of fire resistance. Also, when unplastered lining materials are used there is the difficulty in dealing with the joints satisfactorily, the surfaces may not be hard enough to resist the impacts of normal wear-and-tear, and, if uneven in texture, may hold dust.

113. Whilst it is appreciated that the vermin danger can be exaggerated, and that education in personal hygiene, ample hot water and more light can all contribute towards removing the danger, nevertheless the Committee is unable to recommend the use of linings with air-space for general housing purposes. It believes, however, that with the development of adhesives for the fixing of such boards these disadvantages may disappear.

WALLS: THERMAL INSULATION

114. The control of thermal movements in external walls is seldom effected by the insulation designed for favourable internal conditions, and the use of internal linings will have little or no value for this purpose. Any substantial length of wall should permit the expansion to be taken up in the joints between units, such as would occur normally with brickwork built in lime mortar.

INTERNAL WALLS

115. Internal walls are seldom exposed to conditions that call for special attention to insulation. They should, however, be designed so that their surfaces provide similar response to the internal heating conditions as the inner surfaces of the external walls of the same room. The thermal transmittance value of an internal wall may be important where the wall separates a warm south or heated room from a cold north or unheated room. Breeze concrete slabs or hollow clay blocks 3-in. thick are better retainers of heat than 4½-in. brickwork. Other good forms of partition are studding lathed and plastered both sides, hollow blocks of diatomaceous earth, and light-weight plaster slabs.

WINDOWS

116. As noted in paragraph 104, windows account for a significant proportion of the heat loss from warmed rooms. The insulating value of a single sheet of thin glass is very low compared with the remainder of the wall area of buildings, and double-glazing, though it makes a substantial improvement, still leaves the window as a major source of heat loss. Insulating glasses are marketed but at the present time they are opaque. Shutters and heavy curtains give useful insulation to windows after nightfall when heat losses are greatest, and leave the window unobstructed in daytime to allow the maximum gain of solar heat. Some data is needed to enable the degree of insulation afforded by shutters and curtains to be computed.

117. The importance of air infiltration as a source of heat loss has been discussed in paragraph 104, the crevices round opening sashes, if steel or wood, are an important cause of heat loss and a source of draughts. These crevices will inevitably occur, their extent depending upon the quality of the workmanship and materials. They are also caused by warping or shrinkage of timber, paint films or dust preventing tight closing, and sometimes by defective design.

118. For wood casements, deeper rebates and a form of interlocking tongue would make an improvement, so also would deeper parting beads of sash and box frame windows lined with soft rubber or felt.

119. It is almost impossible to prevent condensation on the inside of single-glazed windows, and where large windows face a cold aspect it is recommended that provision should be made for collecting the condensation water at the foot of the glass, and for draining it away by means of a throat or channel in the frame or other sill to outlets.

120. Double-glazed windows are not so subject to condensation as single-glazed windows, but the trouble may occur occasionally. Provision should be made for collecting the condensation water and draining it away, particularly from the air-space between the sheets of glass where this space is not completely sealed from the surrounding air. Whilst in theory a sealed air-space is the most effective as a check to thermal loss, this is generally very difficult to achieve in practice.

DOORS

121. The crevices round doors are also an important cause of heat loss, but if hung on rising butt hinges or fitted with a slight threshold, a useful improvement is obtained. Otherwise the problem is one of planning, and useful advantages may be gained by the careful placing of doors and by introducing vestibules to check the movement of heat and air at external doors.

FIREPLACES AND FLUES

122. The detailed construction of fireplaces does not come within the terms of reference of the Committee, but valuable information can be obtained from *B.R.S. Questions and Answers* (4th Series) No. 3.

123. As a general principle, the grouping of fireplaces and flues together within a house, and not as part of the external walls, will conserve heat and prevent loss by transmittance to the open air. Fireplaces and chimney stacks forming part of the external walls on the north or other exposed side of a house can be the source of substantial heat losses. Solid brickwork 9-in. thick behind a fireplace is not sufficient in these positions, and it is better to carry a cavity across the width of the fireplace with a $4\frac{1}{2}$-in. brick outer skin and air-space, in addition to the 9-in. solid behind the fireplace. Alternatively, $13\frac{1}{2}$-in. solid brickwork is satisfactory. Similarly, on the exposed sides of a house, flues with $4\frac{1}{2}$-in. brickwork facing are not satisfactory, and should have a thickness of 9 in. or other thermal equivalent on the exposed side for the full height of the living rooms against which the flues abut.

SOUND INSULATION

(See Appendix II for the Principles of Sound Insulation)

CONSTRUCTIONAL PRECAUTIONS

124. In all types of discontinuous or semi-discontinuous construction, great care must be exercised to see that careless workmanship does not destroy the efficiency of the design. For instance, a small solid connection such as a nail driven through both sides of a hollow wall, or plaster extrusions which connect, will have the same effects on sound resistance as bridging across a cavity wall has on weather resistance.

125. Conditions at the junction between windows and outer walls require careful consideration as rigid attachment will encourage development of vibration. Common measures such as the insertion of metal windows into wood surrounds are advantageous.

126. Sound energy can be transmitted along "flanking" paths as at the junction of partition and outer and corridor walls. The principle of discontinuity should be carefully observed at these points. Enough energy to cause trouble will leak through cracks under doors or round badly finished holes for pipes, and cracks in plaster and masonry work.

127. Attention should be given to the design of doors and methods of door closing to prevent slamming and the passage of airborne sounds. It is suggested that rebates should be lined with continuous rubber or other resilient insets or draught stripping. Methods of self-closing which will eliminate slamming and keep the door tight-fitting should be used. In many instances this would cut out the need for latches, which are a source of noise.

128. Where exclusion of noise is very important the insulation value of the door should be at least that of the wall in which it occurs. This may mean that doors of double construction with insulation will be required.

129. The stability of discontinuous construction will always present difficulties, as too much rigidity in fixing may encourage vibration. Generally the fixing of large panels is not so important as that of small, on account of the weight of the former. The ends of partitions should be laterally supported either by being housed in a continuous insulated groove formed by chasing the return wall, or by suitable cover moulds fixed to the return wall. Similar cover moulds fastened to the ceiling should be provided at the tops of such partitions.

130. Care should be taken in the selection of the type of insulation used under partitions in order to prevent settlement and consequent cracking. (See the section on Strength and Stability.)

FIRE RESISTANCE

SCOPE OF REPORT

131. A joint Committee of the Building Research Board and Fire Offices Committee is considering the subject of Fire Grading of Buildings, and will presumably deal with all questions relating to contents, planning, means of escape, fire-fighting equipment, and services, etc. The notes in this Report are therefore confined to certain aspects of construction only, which form part of the general measures of passive defence against fire.

GENERAL PRINCIPLES

132. The precautions to be adopted in the design and construction of buildings to reduce fire hazard are under consideration by the Committee referred to in paragraph 131, and this body has issued an Interim Report but has not yet concluded its studies. It is understood that the broad principle which is likely to be enunciated is that the degree of protection to be required in the structure of buildings should be related to the fire load—the total quantity of combustible material available to cause a fire—appropriate for the occupancy of the building. Thus, relatively low standards of structural protection will suffice for low hazards, and the higher standards will be required for buildings containing large quantities of combustible material. The standards of protection to be called for in the building structure are likely to be those laid down in *B.S.* No. 476-1932, which grades structural materials under five classifications according to the period of resistance under specified tests as follows:

A	B	C	D	E
6 hours	4 hours	2 hours	1 hour	½ hour

FIRE HAZARDS

133. There are, in general, three forms of fire hazard, personal, structural, and external or exposure hazards. The personal hazard relates to the risk to the occupants of a building arising from fire in the construction, which might ignite quickly and cause personal injury or prevent escape, such as might arise from combustible wall and ceiling linings. The structural hazard relates to the risk to the stability of the building itself, and it is the general principle that an endeavour should be made to confine the outbreak to certain defined sections of the building by means of incombustible barriers in the form of walls, floors, and protected openings. The exposure hazard relates to the risk of a building catching fire from an external cause, such as a fire in an adjoining or opposite building, and is therefore concerned primarily with external covering.

EFFECTS OF FIRE ON BUILDING MATERIALS

134. It must also be remembered that even building materials of an incombustible nature may nevertheless fail under fire through:

a. excessive expansion causing distortion;
b. differential expansion of components;
c. chemical action; or
d. failure of the supporting structure.

WALLS AND PARTITIONS

135. In general, it can be said that solid load-bearing external walls of normal materials satisfying the conditions of strength, stability, and weather resistance will usually provide sufficient resistance to fire. Cavities, particularly if ventilated, can form paths for the spread of fire, which is one reason put forward for the unpopularity of cavity walls in some countries abroad, and the development of a method of inserting fire-breaks in such cavities, without destroying the other qualities of the cavity, is needed. This is particularly important in forms of framed construction incorporating wide cavities between the inner and outer skins which may be used in post-war building. Also, linings used for the purpose of insulation, with an air-space behind, can be the cause of the spread of fire through the air-space as well as along the surface of the lining material if not incombustible.

136. The degree of fire resistance of non-load-bearing walls and partitions must be related to that of the supporting structure. For instance, the support of concrete block partitions upon wood, or uncased steel beams is as much to be deprecated as the support of floors on stud partitions.

137. Party walls between buildings must be dealt with on the principle that they should provide protection amply adequate for the hazard presented by the occupancy. In the case of framed structures with combustible materials used in the framework or in the outer or inner linings, it is important that the cavity should be properly fire-stopped to prevent the spread of fire in the cavity. The normal 11-in. cavity wall is itself so highly fire-resisting that the cavity in such walls can hardly constitute a path for the spread of fire. Party walls should be carried up and bedded solid against incombustible roof coverings; although this point is required by the building regulations, it is often badly done. It is also no uncommon occurrence to find put-log holes in party walls inside roof spaces which have not been filled in.

138. The following are examples of the fire resistance as defined in *B.S.* No. 476-1932:

MATERIAL	THICKNESS	GRADE
Brick. Clay / Sand lime / Concrete	9″	A
Concrete	4½″	D
Solid concrete, precast or mass *in situ*	3″	E
	6″	C
	9″	A
Reinforced concrete (average)	3″	D
	6″	C
	9″	A
Brick cavity wall	11″	A
Cavity wall of 4½″ brick, 2″ air-space, and 3″ concrete block	9½″	B
Foamed slag concrete, plastered both sides	2½″	C

SECTION II. SPECIAL REQUIREMENTS

DOMESTIC BUILDINGS

STRENGTH AND STABILITY

139. When considering the subject of dwellings arranged in blocks of flats, the Committee noted, from information placed before it, that where the flats were not more than five storeys high, solid load-bearing walls in accordance with existing by-law requirements were usually cheaper than framed construction with non-load-bearing walls.

WEATHER RESISTANCE

140. The Committee is of the opinion that the 11-in. cavity wall with brick external face is likely to hold its place on account of its reliability in the exclusion of weather, low maintenance cost, and reasonable heat insulation.

141. Hollow block walls and cavity walling in brickwork are suitable for non-load-bearing panels in framed buildings, and where these are of cavity construction the use of hollow or lightweight blocks for the inner leaf is recommended as reducing the weight to be carried.

142. Reinforced concrete wall panels have been used in the construction of flats. With suitable thermal insulating linings, such panels have given satisfactory service. The problem of the external appearance of reinforced concrete walling has not hitherto been solved satisfactorily in this country. This is receiving consideration by the Study Committee on the Architectural Use of Building Materials.

THERMAL INSULATION

143. Walls should be designed to reduce the loss of heat in accordance with the Standards referred to in paragraph 99. In most cases Standard A will be applicable, because if heating is by uncontrolled appliances, the recommended values can be attained by normal good construction except for external walls to living rooms, where additional insulation is required. For external walls generally, the 11-in. sealed cavity brick wall plastered internally is adequate, but for the living room one of the inner leaves referred to in paragraph 108 (a) should be substituted.

144. For small houses, where the living rooms are usually the only room heated, the extra cost of double-glazing the windows is probably justified, particularly in exposed situations. It should be possible to design windows capable of taking double glass without serious increase in the total cost of the building. Storm sashes—the American variant window—may perhaps have a useful application.

145. For example, in a normal living room with an open fire, approximately 20 per cent of the heat loss would be through the window, and another 20 per cent by air circulation up the flue, so that insulation of the walls and floors has a value relative to some 60 per cent of the total heat loss. An examination of a normal living room of 180 sq. ft. area showed that insulation having a capital cost of £12 over normal house construction could result in a saving in fuel in the region of £1, 10*s*. per annum at 1939 prices.

SOUND INSULATION (See Appendix II for General Principles)

146. The required insulation between dwellings is given in *Post-War Building Study No.* 14 (*Sound Insulation and Acoustics*) as 55 to 60 decibels. This value

is above the 9-in. party wall, which is therefore inadequate—a fact well known to the public. The Committee recommends therefore that party walls should be of cavity construction. The cavity should run through the chimney breast as well. Where back to back chimneys pierce the roof and come together in one stack, a horizontal layer of insulation such as asbestos cloth should be inserted at the point where the cavity is stopped. This could be at the level where the damp course is normally inserted and be combined with it to form the damp course itself.

147. The living room is the focus of activity in the house and tends to be the noisiest occupancy. A moderate degree of insulation for the other rooms in the house is, therefore, desirable. Practical considerations make it impossible to demand universally a higher standard of insulation than that given by a timber board and joist floor with plaster ceiling on lathing, and this fixes the value at about 45 db. This value is readily obtainable in partitions by $4\frac{1}{2}$-in. brick plastered or by stud partitions with lath and plaster on both sides. For the separation of living rooms in adjacent houses a higher standard of insulation is desirable and this is set at 55 db., which is higher than that afforded by the untreated 9-in. solid brick wall. By battening out with battens supported by felt insulated clips and lining with plaster on lathing, the solid wall may just be raised to the required standard.

148. Where it is possible to achieve a combination of the cavity party wall and the insulation of the living room from other rooms in the house, the transmission of loud radio and speaking noises will be reduced to an intensity where they will not affect the privacy of neighbours. In the opinion of the Committee this method should be followed in preference to planning—particularly in the case of semi-detached houses—entrances and kitchens in the middle and living rooms outside. Plans based on this principle give large areas of outside walls to living rooms (necessitating thermal insulation in any case) and reduce the amount of outside wall available for kitchen premises where ample means for obtaining natural ventilation are necessary, and also result in service entrances being taken across the backs of the house, thus destroying the privacy of the living rooms and gardens.

149. Between bedrooms and service rooms, and bedrooms themselves, insulation requirements need not be so rigorous, and it may be taken that plastered breeze block partitions, for example, offering a reduction of 35 decibels, will suffice.

150. The tendency to use built-in fittings may lead to their taking the place of partitions altogether—*e.g.* banks of wardrobes between bedrooms. It is desirable that typical constructions of this kind should be tested so that standards of insulation may be prescribed.

FIRE RESISTANCE

151. The Committee is of the opinion that ground-floor partitions or other forms of construction constituting the main internal support to the upper floor should be constructed of materials which offer a reasonable resistance to fire. Also, for two-storey houses, the Committee considers that 11-in. cavity brick walls have a sufficient degree of fire resistance for use as party walls.

SCHOOLS

STRENGTH AND STABILITY

152. Walls for schools are often constructed in too permanent a form, and insufficient consideration is given to the continuous development of educational requirements. School buildings should be designed so that alterations of arrangements can be readily carried out. At the same time it must be borne in mind that there are special considerations for metal and woodworking rooms and other parts necessitating loading conditions akin to commercial buildings.

WALLS: SPECIAL REQUIREMENTS

WEATHER RESISTANCE

153. The requirements for schools do not differ greatly from these of domestic buildings, and the same standards of wall construction are generally applicable.

THERMAL INSULATION

154. Daylight requirements in school classrooms usually necessitate the whole of one side wall to be window space, and roof lighting may be added additionally, so that additional expenditure on thermal insulation of walls over the standard required for houses cannot be justified.

SOUND INSULATION

155. It is not the intention to deal with acoustics in this Report, as the subject is treated in text-books and in the Reports quoted in Appendix II. Attention is drawn, however, to the desirability of using sound-absorbent materials to ceilings and upper portions of walls in classrooms, so that the reverberation period may be cut down to 1 second at 500 c.p.s.—simple methods for calculating this can be found in *Post-War Building Study No.* 14 (*Acoustics and Sound Insulation*). The tendency to encourage the use of hard-wearing materials and finishes in classrooms for easy maintenance and the extensive use of glass in side walls has resulted in excessive reverberation. Sounds are reflected from the hard surfaces causing echoes which greatly confuse the hearing of speech.

COMMERCIAL BUILDINGS

156. The use of frame construction for building shops, offices, and stores is now very general, but the use of ordinary load-bearing walls is sometimes cheaper for buildings up to five storeys in height.

157. The various forms of external surface finish are referred to in detail in *Post-War Building Study No.* 18 (*Architectural Use of Building Materials*), to which reference should be made.

WEATHER RESISTANCE

158. The situation and exposure of tall commercial buildings may call for special treatment of the external wall. Hollow wall construction may be necessary, or the provision of a special surface treatment be desirable. Developments in the construction of framed buildings may lead to the types of wall panels hitherto used being rejected in favour of thin panels which lessen the dead weight to be carried by the structural framework.

THERMAL INSULATION

159. In buildings that are centrally heated, much fuel and labour can be saved by proper thermal insulation. The external walls and roofs should be constructed to the "U" values found appropriate after relative costs of analysis of heat and heat insulation. Also, the use of double windows on north or other exposed aspects is well worth consideration for their thermal insulating properties, in addition to their value for sound insulation.

160. The only special thermal problem that shops present other than the general problems relating to commercial buildings, is in connection with condensation in the windows. During the winter condensation frequently forms on the inner surfaces of the large sheets of plate glass used in shop windows, obscuring the view of the goods displayed, and sometimes causing damage. This difficulty is particularly common in new buildings until they have dried out.

161. There are various treatments, such as de-humidifying the air in the shop by air-conditioning, which is seldom possible or satisfactory; or by enclosing the

display space behind the windows with an airtight enclosure for the full height of the floor. This latter solution is frequently used, and gives satisfactory results provided that the enclosure has reasonable thermal insulating properties, so that the air behind the window does not rise to the temperature maintained within the shop, and that the access doorways are close fitting. Materials such as wood panelling or fibreboard are satisfactory but glass causes difficulties, and if required should be accompanied by air vents in the stallboard; these vents have the disadvantage of admitting dust, which is excluded by the solid form of enclosure.

162. In shops displaying goods with a high polish (silver, etc.) double check rebates are usually provided all round access doors. In shops where water-containing goods are displayed (fish, vegetables, flowers) the thermal insulation of the enclosure and the ventilation of the enclosed space are both important to prevent condensation.

SOUND REVERBERATION

163. The note on reduction of hard surfaces to the walls of schools should be observed particularly for rooms housing noisy machines.

FIRE RESISTANCE

164. This is being dealt with by the Fire Grading Committee.

AGRICULTURAL BUILDINGS

165. It is suggested that reference be made to *Post-War Building Study No.* 17 (*Farm Buildings*).

STRENGTH AND STABILITY

166. Whilst the requirements for agricultural buildings do not differ greatly from those of domestic buildings, provisions against the lifting effect of wind and exposure to the full force of gales must be taken into account. Also the pressure which may be exerted by stackage requires consideration in some cases.

WEATHER RESISTANCE

167. For storage buildings for seed or chemical manures, dryness and absence of light is required (in addition to an equable temperature), and 13½-in. solid brickwork unplastered or 11-in. cavity brickwork should be satisfactory.

168. For other storage buildings (barns, implement sheds, etc.) a reasonable degree only of weather resistance is necessary, sufficient to protect the inside from extremes of temperature.

THERMAL INSULATION

169. For residential buildings (farmhouses and cottages) the recommendations relating to houses would apply, but with greater force owing to the exposed positions in which these buildings are often situated.

170. For storage buildings for seed or chemical manures an equable temperature is required, and it is suggested that external walls should have a "U" value of not lower than 0·35 (such as 13½-in. brickwork unplastered).

171. For other storage buildings (barns, implement sheds, etc.) the only thermal protection required is from extremes of temperature, and lower standards should be sufficient, such as 0·60 (4-in. ballast concrete).

172. For stables, dairies, cowhouses, and piggeries, slightly less insulation than is required for houses should be satisfactory, such as 0·40 (9-in. brickwork plastered).

SECTION III. RECOMMENDATIONS

GENERAL

173. The Committee recommends that:

1. The methods of design of foundations for domestic buildings should be thoroughly reviewed with a view to more scientific determination.
2. Existing regulations for loads on structures and permissible stresses allowable in the various structural materials should be reviewed with a view to effecting economies.
3. For non-load-bearing panels in framed buildings, the use of either hollow block walls or cavity walls in brickwork with hollow or lightweight blocks for the inner leaf.
4. Strong cement mortars are not suitable for the bonding of hollow clay or similar walling blocks. Cement-lime mortars should be used, but the strength of the mortar needs special consideration in positions exposed to the force of gales.
5. *B.R.S. Bulletin No.* 16, *External Rendered Finishes*, should be studied for methods of external rendering.
6. Further developments in the design and manufacture of interlocking blocks for external wall construction should be encouraged.
7. Thermal insulation and sound insulation should be given far greater consideration than they have received hitherto.
8. The revision of the by-laws to permit the cavity construction of party walls should be undertaken.

STANDARDS

174. 1. The Committee has noted that a technical Committee of the B.S.I. has published a Standard Specification for strength of brickwork and masonry, and suggests that a Code of Practice governing the stability of walls generally, should be prepared.
2. A British Standard is required for galvanized wall ties.
3. A British Standard is also required for hydraulic limes.
4. A Code of Practice should be formulated giving design rules, taking into account transverse strength of block and slab partitions.
5. A Code of Practice is needed for lime mortar and cement-lime mortar.

RESEARCH

175. The Committee recommends that research and development be undertaken relating to:

1. The restraint and rigidity given to solid load-bearing walls by cross walls and floors with a view to the determination of practical rules.
2. The use and application of reinforced brickwork.
3. The possibility of economizing in the frame of a framed building by making the external enclosures self-supporting.
4. Discontinuity of structure, which seems essential for sound insulation. Information is required as to the effect on stability in making these arrangements, and as to the measures which should be adopted in the practical detailing of structures.
5. The effects upon partitions of the distortion of multi-storey framed buildings, such as the deflection of floors.
6. The possibility of giving rules for exposure in terms of rainfall, humidity, and wind for various localities, on the lines of the work already done in the case of heat transmission.
7. The proper spacing of wall ties in cavity walls.
8. The use of magnesian limes.

PART II. FLOORS

SECTION I. GENERAL PROPERTIES

STRENGTH AND STABILITY

SUSPENDED FLOORS

176. Reference has already been made to the desirability of reviewing by-laws and Codes of Practice with the object of effecting structural improvements and economies, and in this connection suspended floors should be examined.

SUPPORT FROM SOIL

177. Attention is drawn to the construction of floors direct on the soil, especially in cases where such floors are required to support concentrations of load. There is a need for practical rules enabling the principles of soil-mechanics to be taken into account, especially in the case of made-up ground.

178. The design and construction of the many different types of floors has been considered by the Committee, and attention is drawn to the following:

179. As regards open-joisted timber floors, the *Forest Products Research Bulletin No.* 1, *Dry Rot in Wood*, Second Edition, H.M. Stationery Office.

180. In houses, the method of supporting the hollow precast unit type of floor on relatively thin supporting partitions, needs solving in a practical manner.

181. Reinforced concrete floors are frequently damaged by indiscriminate cutting away for services, a procedure which in any case is wasteful in labour. This should be overcome by pre-planning of the services, and this procedure is strongly urged for all types of floor construction.

INCOMBUSTIBLE FLOORS

182. All the various types of incombustible floors were at one time in general use, both in framed and non-framed buildings, but the relative lightness of the hollow types has in recent years caused one or other of them to be preferred for framed buildings. The filler joist type of floor, with solid concrete in-filling, because of its heavy weight is more suitable for use in non-framed buildings, where the walls of schedule thickness to comply with by-laws usually have an ample margin of strength. This type of floor with hollow in-filling of clay or concrete pots is less open to objection from the standpoint of weight, and also has the advantage of being constructed without shuttering. Solid reinforced concrete floors are heavy as compared to those of hollow construction, but they have the advantage of being free from pattern staining. In the use of hollow precast units in floor construction, economy in design can be obtained by arranging for the provision of steel continuity rods grouted into every joint between units over bearings so that in the completed work the conditions approximate to a monolithic floor.

183. Improvements in the design of hollow reinforced units are required to provide lateral reinforcement to distribute local loads like the legs of heavy pieces of furniture, safes, etc. The provision of light reinforcement in the topping is one method.

TIMBER FLOORS

184. In assessing the loads on joists, allowance should be made for the distributive effect of boarding as serving to spread concentrations of load from heavy pieces of furniture and partitions.

185. The proper grading of timber and its adequate kiln drying are important factors in ensuring a satisfactory life and behaviour of the floor, and attention is particularly directed to this point. (See paragraph 179.) Unseasoned timber will develop marked deflections as it seasons *in situ* under load, and will be vulnerable to fungus attack.

STAIRCASES

186. Economies could be effected in the design of reinforced concrete staircases, especially in the cantilever type composed of separate steps, by using hollow precast construction.

187. Attention is drawn to the serviceability of erecting the staircases for framed multi-storeyed buildings at the same time as the framing is erected. Where subsequent fire risk is slight, flights composed of pressed steel stringers, treads, and risers, formed to take subsequent finishings, have been successfully used for this purpose.

188. The provision of external fire-escape staircases calls for reconsideration. Such staircases are usually constructed of an uncased steel framework, with cast iron treads, risers, and landings. It is difficult to keep these staircases efficiently protected with paint, and in many cases deterioration has occurred as a result of corrosion.

189. Wherever possible the problem of escape from fire in buildings should be dealt with in such a way that escape staircases can be situated within the building.

DAMP RESISTANCE

EFFICIENCY AND DURABILITY

190. Unsatisfactory damp resistance in a floor built upon the earth will affect the use of the building and may injure the health of the occupants. Also, the durability of a floor is largely dependent on the success of the precautions taken against rising damp, as otherwise certain materials are liable to deterioration, and, where timber is employed, to the growth of dry rot, fungus, and consequent decay.

THERMAL INSULATION

191. Heat loss through a floor on the earth may be increased by dampness of the materials in its construction. In an open-joist ground floor the ventilation necessary to control humidity in the space enclosed, is a disadvantage from the standpoint of thermal insulation.

CONSTRUCTION OF GROUND AND BASEMENT FLOORS

192. A layer of concrete over the site should always be provided. This should be at least 6 in. in thickness if of ordinary concrete, and 4 in. in thickness if composed of concrete which is well graded. This practice is not, however, common in Scotland, where it is more usual to lay 4 in. of hardcore or furnace clinker covered with $\frac{1}{2}$ in. of unfinished asphalt.

193. Floors of timber joists on sleeper walls should be provided with ample ventilation by means of air-bricks, and should always have a damp-proof course immediately under the timber plates on the sleeper walls, together with a damp-proof course at the same level in the main walls. Where this form of floor is used adjacent to a solid floor, as is often the case for a kitchen, scullery, or coal store, care should be taken to form ventilating trunks, usually by means of drain-pipes under the solid floor, so that cross ventilation of the open joist floor is maintained. Care should also be taken to see that at the junction between the solid and open joist floor the timbers of the latter are protected from dampness, usually by an additional depth of concrete around the edges of the solid floor. The sleeper walls should always be built with an adequate number of openings to ensure the ventilation of the under side of the floor.

194. The solid ground floor with wood finish has been much used in the inter-war period, but has given trouble in some cases with dry rot. This, however, is not an insoluble problem, and solid floors with a surface finish of boarding on a solid base can be expected to give satisfactory service if a waterproof membrane is provided immediately under the boarding, and the other recommendations laid down in *Forest Products Research Bulletin No.* 1, *Dry Rot in Wood*, Second Edition, are followed.

195. While both open-joist and solid floors may be adopted for ground floors, the choice being governed very often by the levels of the site, solid floors should always be used for basements and for floors below ground level on two or more sides.

THERMAL INSULATION

196. The values of thermal transmittance coefficient "U" recommended by the B.R.S. for ground floors are 0·15, both for the Standards A and B referred to in paragraph 99.

197. The difference between the temperature of the ground, or the air below the ground floor, and that inside the building will cause heat to flow through the ground-floor structure, and this loss of heat can be considerable. The normal ventilated timber joist floor commonly used in houses does not provide sufficient insulation, and it is usually easier to make an improvement by using a suitable type of floor finish on the solid type of floor than to increase the insulation of the ventilated type.

198. 1-in. thickness tongued and grooved boarding on creosoted dovetail battens, or 1-in. wood blocks, on an $\frac{1}{8}$-in. layer of bitumen immediately under the boards or blocks, on 4 in. of foamed slag or clinker concrete and 2 in. of ballast concrete, on hardcore, is estimated to give a "U" value of 0·14, and to show a substantial saving of the heating cost as against the normal pre-war ground floor of timber joist construction.

199. Rising damp may lower the thermal resistance of a solid ground floor, and, in the case of a ventilated ground floor, the free circulation of air necessary to ventilate the enclosed space will aggravate the trouble.

200. There is room for the development of jointless floor finishes for domestic buildings which could be laid direct on concrete, and which would not be so hard or cold to the tread as granolithic, tile, or similar coverings.

201. Intermediate floors of usual types with plaster ceilings and boarded top surface provide sufficient resistance to the passage of heat in most normal circumstances, and extra insulation need only be added where special conditions apply.

But floor surfaces of intermittently heated rooms should be formed of materials having as low a thermal capacity as possible, and ceiling surfaces should respond suitably to the heating requirements, as the temperature of floor and ceiling surfaces has an important effect upon the thermal comfort of a room.

202. If the ceiling surface has a high thermal capacity, and is exposed to rapid air changes as may be the case in kitchens, bathrooms, and living rooms where the heating is intermittent and the room above unheated, condensation may occur. In circumstances of this kind the ceiling surfaces should have a low thermal capacity, but where this is undesirable for other reasons, or is insufficient to eliminate the trouble, additional ventilation or a heating unit near the ceiling may be necessary.

203. Pattern staining may also occur, when the floor construction has abrupt changes in conductivity. (See Part III, paragraph 248.)

SOUND INSULATION

204. Where resistance to airborne sound is important, the normal range of concrete floors can give moderate insulation of 45 to 50 db. without additional treatment. This is sufficient for most purposes but leaves something to be desired for floors separating living rooms and flats. Floating floor finishes, which can be applied reasonably economically, will usually raise the insulation to the required level. Timber board and joist floors with lath and plaster ceilings will give slightly lower results than the normal range of concrete, and will also need the floating floor finish to obtain the desirable standards of insulation for separating living rooms in flats. (See paragraph 301.)

205. When floating floor finishes are used, care in detailing is necessary to avoid the bridging of the resilient layer at skirtings, door openings, and the passage of services through the floors. Nailing through the resilient covering is likely to nullify entirely the useful effect of a floating floor against the transmission of sound. There is a great temptation to drive a few nails here and there to locate joists and battens when the floor is being put down and supervision is necessary to ensure that, if used, they are drawn before completion. The durability of resilient media is important. They must retain their resilience over a long period of use and must not be of such a nature as to deteriorate rapidly under effects of attack by insects or damp.

FIRE RESISTANCE

TIMBER FLOORS

206. Timber board and joist floors have normally a low grade of fire resistance, but experience has shown that under normal conditions they do not present an undue hazard in small houses of two or three storeys. In fact, with good plaster ceilings or with plasterboard ceilings they have been found to have sufficient endurance to enable the occupants of houses to escape in the event of an outbreak of fire. More than this is hardly essential, though readily inflammable board ceilings should not be permitted. The fire resistance of timber floors can be considerably increased by the use of strongly setting plasters on metal lathing in lieu of wood, by pugging between the joists and by the use of tongued and grooved boarding over.

FLOORS OF INCOMBUSTIBLE MATERIAL

207. Steel joist floors with concrete fillings have proved resistant to fire even when the bottom flanges of the joists have had little or no cover. With reinforced concrete floors the type of aggregate used has been found to be the predominant

factor determining the period of endurance of the floor. Where specially high fire endurance is required, as for warehouses storing large quantities of combustible material, gravel aggregates do not show to the greatest advantage. Crushed brick, limestone, blast furnace slag, and probably igneous rocks of the type which are low in quartz may be expected to give the most satisfactory results. Apart from the type of aggregate, thick concrete slabs will generally be less affected than thinner floor sections.

208. Unprotected steel floor beams, or beams encased in combustible material, offer very low fire resistance indeed. Moderate protection, however, is sufficient to give the resistance required to withstand a burn-out in low hazard occupancies such as flats and offices.

SECTION II. SPECIAL REQUIREMENTS

DOMESTIC BUILDINGS

SOUND INSULATION

209. *Airborne Sound.* As the minimum desirable insulation between dwellings for airborne noises has been given as 60 decibels, and the average value of a solid concrete floor is 50 decibels, while timber joist and boarded floor with plaster ceiling is between 35 to 45 decibels, it is clear that considerable improvement is necessary in the case of floors between flats.

210. These improvements can often be effected by the provision of suitable floor finishes, and values for a number of different treatments are given in the Table in Appendix II of this Report.

211. *Impact Noise.* The transmission through floors of noises set up by impact —footfalls, movement of furniture, etc.—can only be effectively reduced by the use of thick carpets and underlays or, with relatively hard-floor finishes such as boarding, linoleum, rubber carpet, tile or concrete, by means of floating finishes in which the wearing surface of the floor floats on the structural base on a resilient support. (See paragraphs 204 and 205).

SCHOOLS

SOUND INSULATION

212. Special conditions obtain in the case of technical schools and classrooms where wood and metal work is done. Discontinuity and special isolation precautions will be necessary here.

COMMERCIAL BUILDINGS

STRENGTH AND STABILITY

213. The need for flexibility in the placing of partitions to suit letting requirements will require special consideration of the types of floors with regard to the distribution of loads. The Committee recommends that design loading allowances to provide for the unknown placing of partitions need reviewing in order to relate them to varying spans and the direction of span of the floors. The broad generalities at present appear to give rise to lack of structural economy in some cases, and overloading in others.

SOUND INSULATION

214. As the positions of partitions in office buildings can rarely be defined until after the structure is completed and in view of the inadvisability of building partitions off floating floors, the general use of floating floors is hardly feasible: they should, therefore, be confined to special points when conditions are determined. But it is unusual to find any special need for reduction of sound transmission through floors in commercial buildings. Some attention to the sound absorption of ceiling finishes in rooms housing noisy machines, typewriters, comptometers, etc. is often desirable. Such combinations as a busy corridor over a boardroom or a conference room are best avoided by precautions in planning.

AGRICULTURAL BUILDINGS

DAMP RESISTANCE

215. For residential buildings (farmhouses and cottages) the requirements for domestic buildings would apply.

216. For storage buildings for seed or chemical manures, the requirements of dryness will generally necessitate the use of a floor providing a degree of damp resistance equal to that required in domestic buildings.

217. For certain other farm buildings, the degree of damp resistance required may be less than in domestic buildings, and a damp-proof membrane may not be necessary.

THERMAL INSULATION

218. For stables, dairies, cowhouses, and piggeries, slightly less insulation than for domestic buildings is suggested—a "U" value of 0·20 (3-in. concrete on hollow clay blocks).

SECTION III. RECOMMENDATIONS

GENERAL

219. The Committee recommends:

1. That in connection with damp resistance in floor construction the information contained in the *Forest Products Research Bulletin No.* 1, *Dry Rot in Wood*, should be studied and applied.
2. That thermal insulation and sound insulation should be given far greater consideration than they have received hitherto.

RESEARCH

220. The Committee considers that research and development should be undertaken relating to:

1. The use of lightweight aggregates suitable for floor construction, with a view to reducing the weight of solid reinforced concrete floors.
2. The need for more scientific design and fabrication in timber floor construction, with the object of using timber in the most economical way.
3. The possibility of rolling or pressing light steel sections for floor construction.
4. The floor superload allowances for partitions, with a view to formulating rules for the permissible weight of partitions (of variable position) in relation to methods of floor construction.

PART III. ROOFS

SECTION I. GENERAL PROPERTIES

STRENGTH AND STABILITY

DESIGN

221. The design and construction of roofs generally is controlled by by-laws and Codes of Practice and, as in the case of floors, the need for structural economy and development is thought to warrant a review of existing standards.

222. The design of timber roof construction for domestic buildings needs placing on a methodical basis. Roof members should be designed to suit the various roof coverings and the grade of timber available; and the forms of joints should be designed to this end. Nailed connections are satisfactory if designed to take the forces to be transmitted. The numbers and sizes of nails should be specified. Data on the holding power of nails needs reviewing. The extravagant use of timber coupled with haphazard nailing is the antithesis of sound and economical construction.

223. As an alternative to timber construction the use of trusses or tied rafters of light structural steel scantlings, strip-rolled welded steel, or of welded tubular construction to support various types of roofing should be considered.

224. One of the items requiring investigation in connection with strip-rolled or welded tubular steel construction is that of permanent protection against corrosion. The development of alloy steels or the wider use of non-ferrous metals may constitute a solution to this problem.

WEATHER RESISTANCE

225. Roofs are, perhaps, the most vulnerable of all the exterior surfaces of buildings to effects of weather, and care is always necessary in the selection of materials for coverings in order to ensure adequate durability and reasonably low maintenance costs. It is important to know that various types of roof covering are more or less susceptible to different types of weathering agency. Clay tiles are sometimes susceptible to frost action. Slates can be affected by polluted atmospheres in industrial areas. Ferrous metal coverings are liable to corrode when exposed to industrial or seaside atmospheres. Lead is highly resistant to atmospheric corrosion but may be attacked if laid in direct contact with unseasoned hardwoods or with new cement concrete. Asphalt and bitumen coverings are sensitive to ultra-violet light and heat. There is no universal criterion for all materials, and in view of the importance of the weather factor on roof coverings a complete range of British Standards to deal with all types of roofing materials is very desirable.

THERMAL MOVEMENT

226. Movement of the covering, or of the supporting roof structure, has to be provided for so that it may take place without impairing the weather resistance and strength of the roof and the supporting structure. This precaution is always necessary in the case of flat roofs of considerable expanse.

COVERINGS FOR PITCHED ROOFS

227. The efficiency of the various roofing materials depends on their having the requisite pitch, and the building being considered in relation to its situation.

228. NATURAL SLATE can provide a durable and waterproof roof covering. In industrial areas with polluted atmospheres, some discrimination is needed in the choice of slates and their nails. Attention is directed to *B.S.* 680–1936 for *Welsh Roofing Slates.*

229. ASBESTOS CEMENT SLATES are covered by *B.S.* 690–1940, and the specification includes recommendations for laps for normal exposures. These products have become widely used since the last war, and the British Standard ensures a high durability.

230. Good practice in PLAIN ROOF TILING is summarized in the *Code of the Building Industries National Council* (1937), and it is recommended that the Code be adhered to.

231. There have been troubles in the inter-war period with CLAY PLAIN TILES both on account of porosity and disruption by frost. A good clay tile will last for centuries, but a bad one may break up by lamination due to frost within ten to twenty years. Hand and machine made tiles have been affected alike. The *B.S.* 402–1930 deals with the properties of clay marl plain roofing tiles, and in respect of permeability should ensure a thoroughly satisfactory performance.

232. CONCRETE PLAIN ROOFING TILES are the subject of *B.S.* 473–1932, and tiles complying with this specification should be satisfactory in all respects. The inter-war period has seen a very rapid development of this industry, and latterly it has come to be realized that concrete tiles are cheap, and give little trouble due to porosity and frost deterioration.

233. SINGLE LAYER TILING is applied to those designs of tiles which comprise side and end laps so that over the greater part of the roof there is only a single thickness of tile. Clearly such a roof is much lighter than plain tiling and this in turn allows savings in timber. The elaborately designed continental tiles, with their numerous checks to rain, snow, and wind, can be used at much lower pitches than plain tiling, and here again there is a saving in timber.

234. In order of development the single layer tiles began with the pantile in the seventeenth century. THE ROMAN AND DOUBLE ROMAN TILES have been considerably used in the inter-war period. THE INTERLOCKING CLAY AND CONCRETE TILES, *B.S.* 550–1934, as manufactured in Great Britain have given satisfactory service on fairly steep pitches. THE INTERLOCKING CONTINENTAL TILES with elaborately designed and manufactured weather checks have been extensively used, the "Marseilles" and "Courtrai-Du-Nord" being perhaps the best known. They have usually given satisfactory service except when tiles have been stripped by the wind in a few exposed sites. It has to be realized that these light coverings need to be adequately secured in exposed positions.

235. STONE SLATES can form a satisfactory covering, but are heavy and require heavier timber framing.

236. SHEETS OF ASBESTOS CEMENT, CORRUGATED IRON OR STEEL suitably protected with a bituminous covering have been extensively used and are suitable for some classes of buildings.

237. Owing to the inflammable nature and expense of upkeep of THATCH, this type of covering is not recommended.

238. The choice of under-coverings for tiled or slated roofs is governed mainly by cost. The under-coverings vary from the use of battens only to the best practice of boarding, felt, battens, and counter-battens. While in Scotland it is a common practice to lay slates direct on boarding and felt, in England the three underlayers of boarding, felt, and battens are in general use in good class work. Although a roof of tiles on battens only is often adopted in cheap buildings in the south of England, the insulating quality of the roof space is thereby much reduced. Felt and battens are sometimes used, but there is a risk of the felt being torn when being laid. This would be obviated if a suitable reinforced felt was used. Battens on grooved and tongued boarding without felt are sometimes used, but the omission of felt is a doubtful economy. Felt used for roofs is referred to in *B.S.* 747–1937.

239. A roof covered with pantiles, or with plain tiles that are to any extent porous, is not entirely resistant to the penetration of moisture, and there is a risk in using both boarding and battens as any moisture penetrating the roof covering and running down the boarding will be held up on the battens. These being damp for long periods may become rotten and their ultimate decay may in the course of years render it necessary to strip, re-batten, and re-lay the roof covering. With coverings that are unduly porous it is best to provide either battens only or battens and felt.

COVERINGS FOR FLAT ROOFS

240. For flat roofs of timber the customary roofing materials laid on boarding firred to falls are as follows:

a. Copper.
b. Lead.
c. Zinc.
d. Several layers of bituminous felt with some other material such as tar macadam as a top finish.
e. Asphalt.

In cases where coverings (d) and (e) are adopted it is possible instead of boarding to use asbestos cement and other forms of decking to receive the roof covering.

241. Asphalt mastic was formerly considered to be the best form of flat roof covering, having an extremely long life. There have, however, been failures after a relatively short period of years, possibly because the mastic was prepared not by blending natural rock and lake asphalt but by mixing asphaltic bitumen derived from petroleum sources with graded mineral aggregate; possibly because of failure to adjust the method of use to changes in roof construction. The lack of a standard for asphalt mastic also contributed to the growing use of a covering composed of several layers of bituminous roofing felt, as classified in *B.S.* 747–1937, finished usually with grit, but sometimes with a topping of cement and sand, tile, etc. and requiring periodic maintenance. Recently, however, *B.S.* 988–1941 has been published for a type of asphalt mastic not based on natural rock asphalt, and mastics made to this standard are known still to be satisfactory after the greater part of a decade. During the transition period that will follow the end of the war built-up bituminous roofing felt and asphalt mastic to this specification, laid with a thick hair felt between it and the constructional roof, can be recommended. When the components of natural rock asphalt mastic are again available, this type is likely to regain its position as a permanent roof covering, especially as *B.S.* 1162–1944 for such mixtures is now ready for publication. Asphalt mastic can also be used on sloping surfaces of pitched roofs, but should be provided with wire mesh or other mechanical device to obviate any tendency to creep. During the war coal-tar pitch has been substituted for asphaltic bitumen in felts and, on an experimental scale only, in mastics, but its continued use after the war is in doubt.

THERMAL INSULATION

SOLAR HEAT

242. The heat of the sun may have an important effect on the temperature inside a building during summer if suitable insulation is not provided. Heat from the sun may also cause serious expansion of the roof structure itself.

AIR LEAKAGE

243. Air leakage may occur through the open fabric of a slate, tile, or sheet roof covering, or through opening lantern or skylights, and so lower the temperature of the enclosed air of the roof structure that water tanks or pipes in the roof space will freeze; it may also cause a serious loss of heat in the building.

TRANSMISSION THROUGH STRUCTURE

244. The loss of heat by transmission through the structure of a roof and its coverings should generally be reduced to a minimum. The following values of thermal coefficient "U" are now recommended by the B.R.S.:

STANDARD A	STANDARD B
Refer back to Part I, Section I, paragraph 99.	
Roof and top floor ceiling 0·30.	Roof and top floor ceiling 0·20.

TEMPERATURE OF INNER SURFACES

245. The temperature of the ceiling surfaces will have an important effect on the thermal comfort of a room (see Part I).

CONDENSATION

246. Where the materials used for the construction of ceiling surfaces have a high thermal capacity, difficulties may be experienced from condensation. In the case of reinforced concrete roofs some additional lining of low thermal capacity and conductivity is considered desirable.

247. It is noted that a certain amount of condensation is unobjectionable, as this will be taken up by the air of the room as soon as the interior temperature rises above dew point. To reduce condensation effectively, the under side of roof structures should be lined with fibreboard, cork, or wood-wool slabs, preferably with an intervening air-space. Condensation can be reduced by ventilation, but this is not considered a complete solution. More research is needed on this subject.

PATTERN STAINING

248. Pattern staining occurs when the thermal conductivity of the roof varies from point to point, as in the case of hollow construction.

249. A lining or false ceiling of insulating material usually provides the solution, but care must be taken to ensure that the supports of the false ceiling do not cause pattern stains of their own. Insulating materials above the roof slab will help by restricting the rate of heat flow through the roof outwards.

STRUCTURAL MOVEMENT

250. Thermal movement is a common cause of defects where roofs are of monolithic construction and insufficiently insulated from the external or internal conditions causing temperature changes. Suitable insulation cannot always be obtained economically by present-day methods, and it may be necessary to make provision at bearings for movement of the slab relative to its supports. See *Principles of Modern Building*, Vol. I (Fitzmaurice).

251. Insulation may be introduced between the asphalt or other waterproof covering and the structural slab or a light surface colour may be provided to reduce as far as possible the entrance of solar heat by reflecting it back. The former method is simple and effective but imposes serious conditions on the asphalt owing to the high concentration of heat. The latter method includes painting, but this is liable to become discoloured and does not wear well where there is traffic. Proprietary tiles stuck down and jointed with bitumastic material or a 3-in. layer of gravel may prove successful if the work is properly carried out. A combination of the two methods will generally give the best results. The incorporation of light coloured grits in the finished surface of the asphalt mastic is a promising development.

PITCHED ROOFS

252. Pitched roofs with tiles, battens, and felt over a plasterboard ceiling have poor insulating qualities. The addition of boarding under battens will improve this, but it is considered that the improvement obtained by laying ½-in. fibreboard or its equivalent above the ceiling joists (in addition to boarding under the battens) is so pronounced that it should be generally adopted. It is estimated that the latter arrangement will obtain a value of "U" of 0·18, and will show a saving of 68 per cent of the heating cost represented by losses through a pitched roof having only tiles, battens, and felt over a plaster or plasterboard ceiling. By concentrating the insulation on top of the ceiling joists, the amount of material required will be considerably reduced as compared with lining the rafters.

253. Pitched roofs should be so constructed that cold draughts will not reach pipes and cisterns. Underfelting is useful in this respect, and beam filling of joists and rafters where they join the external walls will also help. Pipes and cisterns in the roof space should, however, be lagged; if this is not done the whole of the roof should be insulated. *Post-War Building Study No.* 4 (*Plumbing*) should be consulted.

FLAT ROOFS

254. Solid reinforced concrete flat roofs waterproofed externally and plastered internally, and hollow reinforced concrete roofs covered in the same way have poor insulating qualities. The provision of 2-in. lightweight concrete as a screed makes an improvement, but for improvement up to Standard B it is necessary to add 1¼-in. fibreboard or 1-in. cork under the waterproof covering externally and to batten, lath, and plaster internally or to employ one of the alternatives mentioned in paragraph 251.

255. There is no appreciable difference as regards thermal insulation between built-up bituminous felt coverings and asphalt.

256. The roof types having insulation above the main structure provide useful insulation against the effects of the sun, but do not fulfil the requirements for internal conditions so well as those types with insulation below the structural roof. Those types with insulation above and below are the more successful.

ROOFLIGHTS

257. Skylights and lanterns can be the cause of considerable heat losses, and are often the cause of draughts on staircases. The use of laylights can reduce the losses by nearly one-half, whilst the use of proprietary glass consisting of glass silk between thin glass sheets will have an effect of about the same value. (The thermal transmittance value "U" for a skylight is 1·00; and for laylight with lantern over, the value "U" is 0·57.)

FIRE RESISTANCE

258. All roofs are vulnerable to exposure hazard, and an external covering of incombustible material is therefore essential, and is generally required by by-laws except in the case of isolated buildings. A covering of incombustible material is, however, not a complete protection to exposure hazard where there are openings in pitched roof for dormers or skylights, or where there are wide gutters against parapets and chimneys. Although little can be done regarding dormers, skylights should generally be glazed with wired glass, whilst gutters can be protected by a layer of asbestos cement board under the covering.

259. Pitched roofs of timber construction represent a substantial structural hazard, but their vulnerability can be improved by attention to detail. Beam filling at caves should be bedded close to the external covering, and all openings such as trap doors should be flush with plaster ceilings and covered with fire-resisting board. The usual method of resting the trap doors on top of the ceiling joists exposes the joists and linings to fire from below. The value of the plaster ceiling should be fully exploited, and it should be as far as possible imperforate.

260. Similar considerations apply also to flat roofs, particularly those of timber construction. Linings used for thermal insulation, of fibreboard or other combustible materials, are better placed on top of the flat roofs from the point of view of resistance to fire from within the building.

SECTION II. SPECIAL REQUIREMENTS

DOMESTIC BUILDINGS

THERMAL INSULATION

261. Insulation should be designed to reduce the loss of heat through the roof in accordance with the standards now recommended by the B.R.S. (quoted in preceding Section). Standard A can be obtained in a pitched roof having tiles on battens, boarding, and felt with a plaster or plasterboard ceiling. Standard B will generally require an additional lining such as is recommended for external walls (see Part I, Section 1) and this lining is best placed over the ceiling joists. Standard B can be obtained in flat roofs of either hollow tile or solid concrete construction with an additional lining of 1-in. cork or $1\frac{1}{4}$-in. fibreboard.

262. Special consideration should be paid to the heating-up properties of the ceiling surfaces, and materials having a low thermal capacity and a low conductivity are generally most suitable for intermittent heating.

SCHOOLS

THERMAL INSULATION

263. It is necessary to insulate the roofs of school buildings against excessive heat in summer and loss of heat in winter. This applies particularly to one-storey buildings. The whitewashing of the roof (externally) to reflect the heat is also of value in summer, although temporary in effect.

AGRICULTURAL BUILDINGS

STRENGTH AND STABILITY

264. Out-buildings such as barns, cowhouses, etc. have in the past generally been constructed with timber framing, although steel framing has been used for the Dutch barn. The use of timber, often of local growth and supply, seems likely to continue, but the application of precast reinforced concrete offers possibilities

of development. Transverse frames of reinforced concrete, such as the type comprising posts housed in socketed bases with rafters rigidly connected to the posts and pin-jointed at the apex, and other forms, have been found satisfactory for shed construction of moderate span, and suitable for certain types of agricultural buildings.

WEATHER RESISTANCE

265. The roof coverings which have been customary in the past are slates, pantiles, and galvanized corrugated steel, and also, more recently, corrugated asbestos. Slates or pantiles can generally be used on battens only, without boarding or felt, as apart from the cost of these materials, a roof covering on battens only affords the ventilation which is desirable in certain classes of farm buildings. The short life of corrugated steel may be much increased by using a form of this material which is supplied already protected by a coating of fibrous and bituminous materials, and by regular painting. Corrugated steel of the heavier gauges can be laid with widely spaced purlins, whereas ordinary corrugated asbestos sheeting should not be laid at a greater purlin spacing than that given in *B.S.* 690–1940. Forms of curved corrugated sheeting forming part of the roof construction have been found to be satisfactory.

THERMAL INSULATION

266. Storage buildings for seed or chemical measures require an equable temperature and it is suggested that roofs should have a "U" value of not less than 0·55 (such as corrugated asbestos cement, air-space, and $\frac{1}{4}$-in. asbestos cement sheet).

267. Other storage buildings (barns, implement sheds, etc.) only require thermal protection from extremes of temperature and 1·20 should be sufficient (tiles on battens or corrugated asbestos).

268. For stables, dairies, cowhouses, and piggeries slightly less insulation than for domestic buildings should be satisfactory and 0·33 is suggested (tiles on boards and felt).

SECTION III. RECOMMENDATIONS

STANDARDS

269. The Committee recommends that:

A British Standard should be prepared for rock asphalt mastic for roofing.

RESEARCH

270. The Committee recommends that research and development be undertaken relating to:

1. The stresses in pitched roofs of timber, and the consequent minimum size of members.
2. The design of suitable fastenings to materials of a cellular nature such as wood-wool.
3. Alternative materials and methods of forming a weather fillet at the junction of sloping roofs with vertical faces, without the use of metal flashings.

C. LOVETT GILL,
Chairman.

APPENDIX I

EXPERIENCE RESULTING FROM WAR-TIME BUILDING

271. War-time building has been directed to secure the following:

a. Economy in labour.

b. Reduction in the use of materials in short supply.

272. Experience has been gained, therefore, in standardization, prefabrication, transport, and erection, and generally in the use of materials and constructions of a semi-permanent nature. In certain cases, the quality of materials has also been relaxed to economize in imported materials, or for other reasons. Many of the recommendations contained in the Wartime Building Bulletins, prepared under the aegis of the Department of Scientific and Industrial Research, have been tried out.

273. War-time buildings have had to be designed to stringent standards of economy in regard to form, layout, structural sufficiency, and character of external enclosures. Economies in structural design have been brought about primarily by increases in working-stress allowances, and by applying, where possible, the principle of continuity of structure, such as the inter-dependence of reinforced concrete beams and pillars.

274. Economies in the tonnage of steel used have been effected by developing the application of metal arc-welding to the fabrication of structural steel transverse frames, of trusses knee-braced to stanchions, and of three-pinned braced transverse frames comprised of posts integral with rafters. The development of tack-welded and spot-welded cold strip-rolled steel trusses, purlins, and other framings has also effected marked economies in the amount of steel used, but in some instances these savings in material have been achieved at the expense of somewhat increased labour in fabrication.

275. Timber construction has been developed by the application of resin-bonded plywood gussetted joints (glued and nailed) to the construction of light timber roof trusses, knee-braced to posts.

276. Composite construction of transverse frames, such as welded steel trusses knee-braced to precast reinforced concrete columns, has also been used.

277. The permanence of all the above types of construction is still under observation and data regarding long-term behaviour is not yet available. In so far as the welded structural steel and reinforced concrete structures are concerned, including composite structures of these two forms, there is no reason to doubt their normal permanency, although the light structural steel scantlings down to $\frac{3}{16}$ in. in thickness will need careful periodical painting.

278. Regular re-painting is even more important in the case of the strip-rolled steel construction in which nothing thicker than gauge sheet metal occurs. The expense and difficulty of satisfactorily re-painting these light sections *in situ* and

of thoroughly protecting the welded (especially the spot-welded) joints is likely to affect the permanency of this type of construction, but new methods of rust-proofing are being developed.

279. Glued and gussetted timber construction may be subject to deterioration from humidity and cannot yet be regarded as any but a purely war-time measure.

EXTERNAL ENCLOSURES

280. Among the forms of construction used in war-time buildings and hutments are the following:

a. Steel or timber framing covered with corrugated steel, or corrugated asbestos, sheeting.
b. Light timber frames sheeted inside and out with plasterboard protected externally with bituminous felt—all prefabricated.
c. Various forms of sawdust concrete wall panelling cast in flanged panels, and in some cases bolted together, with bituminous jointing materials.
d. Mesh steel fabric partitions rendered both sides *in situ* with cement mortar.
e. Thin pre-stressed twin concrete slabs kept apart by spacers and forming cavity panels for external walls.
f. Cavity walls of 4½-in. outer brickwork and an inner skin of breeze slabs, wood-wool slabs, brick-on-edge, etc.
g. Hollow burnt clay partition block walls.
h. The Fidler wall composed of two skins of tied breeze slabs with a cast *in situ* concrete core.
i. Thin cast *in situ* reinforced concrete walls.
j. Solid 4½-in. brick walls; and solid 9-in. walls.

281. Some of the foregoing varieties, panels between framing of various kinds, were found to be liable to defects resulting from humidity and temperature changes; other forms were found to have a considerable measure of structural permanence, although defective in weather resistance in exposed positions or as regards thermal insulation.

282. The tendency has been to construct long buildings without provision for the movements which result from temperature changes, and in many such buildings the light walls have developed marked cracking. Experience has shown that the limit of continuous length in light construction is from 60 to 100 feet. Buildings over this length should be divided by expansion joints forming a complete break through walls and roofs to allow for temperature movements.

283. Defects have developed due to the lightness in weight of thin walls and roofs and the shallowness of foundations—in general, the lessening of dead weight in temporary buildings tends to permit movement and consequent cracking.

284. Where doorways of normal construction have been provided in light partitions such as brick-on-edge partitions, marked damage of the partitions has occurred due to slamming of the doors. In such cases the door frames should be carried up to the ceiling and be securely fixed.

285. Roofs of hollow precast reinforced concrete units supported on brick cavity walls have given trouble. These roofs have, in many instances, been constructed without topping over the units (in order to lessen the dead wieght) and with the roofing felt laid directly on the units. The absence of thermal insulation has caused movements of the roof as a whole, and secondary movements of the units

themselves, resulting in open joints showing on the under side, in the rupturing of the felt covering, in cracking at the wall bearings, and in the communication of damaging lateral and longitudinal forces to the walls.

286. When a topping of lightweight concrete, 2-in. to 3-in. thick, has been provided over the units, its insulating effect has eliminated or considerably lessened the above defects. In some instances, a partial remedy has been effected by a topping of 2 in. to 3 in. of fine gravel, laid over the felt.

287. If the roof bearings are taken on a layer of felt or paper, relative movement of the roof with respect to the walls takes place and tends to obviate cracking of the walls, but this provision has proved to be only a partial remedy. In temporary hospital wards constructed in this fashion, where ceilings and walls have been plastered, cracking and spalling of the plaster has occurred at the junction of the ceiling and walls, due to the roof movements. Such junctions in the plaster should be avoided and a slip joint constructed at the top of the vertical plaster to allow relative movement.

288. Parapet walls have been fractured and pushed over due to thermal movements in flat roofs; the use therefore of parapets should be avoided in semi-permanent construction.

289. These several defects have occurred only in a relatively small percentage of war-time buildings, but they are indicative of the various troubles to which sub-standard construction is liable.

APPENDIX II. SOUND INSULATION

GENERAL PRINCIPLES

290. Continuity in construction, particularly steel and reinforced concrete frames, the use of lighter more vibrant materials, the development of highly polished finishes, the increased use of wireless and other electrical and mechanical equipment, together with a growing volume of traffic noises, have brought the problem of sound insulation into greater prominence than in the past. The degree of nuisance now caused by noise calls for a more scientific investigation into the problem.

291. In recent years it has become clear that the subject has not received sufficient attention, though it must be admitted that the necessary scientific knowledge of the mechanism of sound transmission has only been developed to the point where it gives a rational basis of design within the last few years.

292. A report on the sound insulation and acoustics of buildings is included in the present series of Post-War Building Studies. Certain of the reports of U.S. Bureau of Standards provide useful information, but these have been reviewed in the preparation of the report referred to above. The problem now is to work out the application of the scientific data available to the practical problems involved in the construction of buildings. Included in the report mentioned above are tables of loudness for outdoor and indoor noises; tables showing standard of maximum loudness of airborne noise for comfort and standards of insulation from impact noise for varying occupancies.

293. The problem for the building designer is to estimate the intensity of intruding noises, to estimate the degree of quiet required for particular occupancies and, by difference, to estimate the degree of insulation to be provided in structures dividing noisy from quiet occupancies. It is not necessary, however, to reduce intruding noise to complete silence and, in fact, it would rarely be possible to do so. Most rooms have a normal sound level, and obtruding sounds have to be sufficiently strong in comparison to create disturbance; for instance, a school classroom or a busy office would not be affected by a sound, the intensity of which would completely upset the quietness of a study or bedroom.

The degree of preventive measures will therefore vary according to circumstances.

294. In the body of this Report reference has been made to desirable standards of insulation expressed in decibels or phons. The reader will, naturally, require some indication of the meaning of these units. The decibel (contracted db.) is a unit of difference in sound energy (not a difference in loudness as judged by the ear), and as human hearing tends to have a logarithmic response, in common with some other senses, the difference in decibels between two sounds is expressed on a logarithmic scale. The decibel, therefore, breaks up the range of sound intensities in steps which are roughly comparable to the hearing of a listener. As a simple illustration of the application of the decibel scale, it may be noted that a difference in intensity between two sounds of 5 db. would be just comfortably apparent to the normal listener; that the normal 9-in. brickwork party wall will give a reduction of about 50 db., and ordinary window glass about 25 db.

295. There are complications in the use of the decibel which it is not proposed to discuss at length here. A unit of hearing varies according to frequency (or pitch) of sound, and the insulation of structures also varies with frequency. The figures given in the body of this Report are average values over a range of frequencies.

296. The phon is a unit not dissimilar in character to the decibel, but it takes into account the idiosyncrasies of the human ear as regards response to different frequencies, and it is used as a measure of "loudness" or "loudness difference" for subjective measurement. For first rough approximations, which is as far as the subject can be taken in this Report, the phon may be equated to the decibel.

297. From the foregoing notes it will appear that it would be injudicious for the novice to attempt to "split straws" in the estimation of loudness or of sound reductions by building structures. Difference of 5 db. indicate a possible trend one way or the other, and differences of 10 db. begin to be significant.

298. Planning to avoid sound disturbance is vitally important. This applies not only to the detailed planning of individual buildings but to siting also. For instance, if a room is required to be quiet it should not face into a noisy street; nor should it be placed next to, or above or below a room where excessive noise may be expected. Similarly, it is undesirable that a residential building should be built immediately adjoining a main road, and when considering siting questions the possibilities of sound deadening by screens of hedges, trees, flanking walls, and areas of lawn, etc. should be borne in mind.

299. By far the most important element in the exclusion or admission of outdoor noise is the *window*. Generally windows form at least one-third of the area of external walls, and with this ratio the windows will determine the amount of noise entering a room and the brickwork or other wall material can be neglected. It

must then be recognized in dealing with any serious problem of external noise, that the treatment possible depends upon whether or not the window is to be open in the hot weather. The sound insulation of the window and the ventilation of the room have to be taken in conjunction. Even quite a small amount of opening reduces the insulation of a window nearly to a negligible quantity.

300. In ascending order of insulation the following window treatments can be adopted:

WINDOW TREATMENT	CONDITION IN ROOM COMPARED WITH OUTSIDE
Open window, in average furnished room.	Just perceptibly quieter than immediately outside.
Window as above but opening reduced to about 3 sq. ft.	Quite appreciably quieter than immediately outside.
Window closed, single 21-oz. glass.	Good enough for the average busy office fronting on a busy street. Not good enough for an important conference room or senior executive.
Window closed, single $\frac{1}{4}$-in. plate glass.	Appreciably better than the above, probably just about good enough for the conference room.
Double window, absorbent reveals, with baffled ventilation openings.	
Double windows, closed, 21-oz. glass, not less than 5 in. apart.	Good enough for all except very critical conditions of quiet when fronting on noisy streets.
Double windows, closed, $\frac{1}{4}$-in. plate glass, 6 in. apart, with absorbent on reveals.	As good as, or better than, the average wall in which fixed. Good enough for very critical conditions of quiet in rooms fronting on noisy streets.

301. It may be noted that the volume of air admitted by the double window with ventilation openings can be much increased if a system of cross ventilation is provided by openings in partitions and walls, so arranged that air can sweep right through the building from outside to outside. With such an arrangement the amount of ventilation afforded by the specially designed double window is probably good enough to give comfortable conditions.

INDOOR NOISE

302. Insulation against indoor noise is difficult and often expensive to obtain by structural means, and it cannot be too strongly emphasized that the first line of defence is to plan buildings so that the need for structural insulation is reduced to a minimum. Sources of noise should be removed as far as possible from places where quiet is needed.

303. With the utmost care in planning, however, there are bound to be situations where insulation has to be provided in the structure, and the task before the designer is to estimate the amount of insulation needed, and to provide structures that do in fact give the required insulation. It is important to recognize that sound transmission in buildings *is always three-dimensional.* The weakest structure (in the sense of sound insulation) will be the link in the chain which will determine the amount of sound transmitted from one part of a building to another. It would be foolish, for instance, to build an elaborate and expensive partition between two adjacent rooms if the floor were continuous between the two rooms and of poor

insulation. It would be reasonable in such a case to make the partition at least as good as the floor but it would be unprofitable to make it substantially better.

304. It is useful to approach problems of structural sound insulation in the light of the mode of sound transmission through different kinds of construction. As a first general subdivision it is useful to distinguish between continuous (homogeneous), semi-discontinuous, and discontinuous constructions. By continuous construction is implied solid structures where the two faces are connected by rigid materials such as solid floor or walls or hollow blocks with frequent web connections. It is characteristic of continuous construction that sound insulation depends on weight but the actual sound reduction in decibels varies as the logarithm of the weight. In effect the insulation of a continuous wall or floor increases by 5 db. every time the weight is doubled. Consequently a stage is soon reached when it becomes uneconomical to obtain increased insulation by increases in weight. The $4\frac{1}{2}$-in. brick wall is worth 45 db. and the 9-in. brick wall is only a little better at 50 db.

305. To consider next the other extreme—discontinuous construction. By this is implied forms of construction where, so far as possible, the opposing faces are not bridged by any continuous rigid link. Complete discontinuity is not possible in a building. In the case of two adjacent rooms it could only be obtained when they were floating in space. The definition adopted here for "discontinuous construction" is where the walls, floor, and ceiling of a room or groups of rooms together, form a shell or box which is independent of the other room, or connected to it, or to the supporting structure by relatively weak or resilient links, and not by any solid or substantial bridge of conducting material. As a working rule for estimating the amount of insulation afforded by a "discontinuous" structure it is reasonable to assume a 25 per cent increase in insulation over a continuous structure of equal weight.

306. In the intermediate category are a number of structures which for want of a better term are described as "semi-discontinuous." These take the form of walls, partitions or floors where the two opposing faces retain a measure of freedom to vibrate, independent of each other.

307. The stud partition is typical of this group, and the essential feature for good insulation is that the facings should be "flabby" and the studs stiff. Plaster on lathing is relatively flabby but board linings tightly nailed tend to be stiff and ineffective as insulation. Anything which tends to reduce the rigidity of the connection of the facing to the studs improves the insulation. A plaster lining "firred out" on a solid wall or partition will give a useful increase in insulation. If the latter are secured in special clips or are felt wrapped in ordinary clips the insulation is again improved. As a working rule for computation of the amount of insulation afforded by semi-discontinuous construction it is reasonable to assume a 15 per cent increase in insulation over a continuous structure of equal weight.

IMPACT NOISE

308. It is customary to express insulation values for impact noises in terms of the improvement offered over standard construction, and the following table gives values for various measures. Roughly speaking impact noises affect floors mainly, and the treatments are additive in effect.

IMPACT NOISE FOR CONCRETE AND TIMBER FLOORS

Improvement in Noise Reduction over Bare Floor Measured in Phons

309.

CONCRETE

	SHARP BLOWS	DULL BLOWS
Bare concrete	0	0
Carpets, etc.:		
$\frac{1}{8}$-in. lino and $\frac{1}{8}$-in. lino on roofing felt	5	5
Wood blocks, thin carpet, or rubber	5	10
Carpet on $\frac{1}{8}$-in. underfelt	10	10
Screeds, 2-in. thick, on following underlays:		
Clinker	5	10
Granulated cork, 1 in.	10	15
Single layer of glass silk quilt	20	20
Glass silk quilt, double layer	25	25
Boarding on battens on following underlays:		
Asbestos pads, felt pads, $\frac{1}{2}$ in. thick	5	10
Felt pads, 1 in. thick	10	15
Glass silk quilt	15	20
Suspended ceilings:		
$\frac{1}{4}$-in. plaster on $\frac{1}{2}$-in. fibreboard on 2-in. by 2-in. battens in clips	5	10
$\frac{3}{8}$-in. plaster on $\frac{3}{8}$-in. plasterboard on battens in felt-lined clips	10	15
No figures are available for metal lath ceiling suspended on metal supports, but their performance appears to be of the same order as the above.		

TIMBER

Normal board and joist floor, lath and plaster ceiling	0	0
Carpet on underfelt	10	10
Plaster on plasterboard ceiling	0	0
Pugging, sand or ashes 10 lb. per sq. ft., or slag-wool 2 lb. per sq. ft.	5	5
Sand or ashes 20 lb. per sq. ft.	10	10
Floor boards on cross battens on glass silk quilt, not nailed	5	5
Floor boards on glass silk quilt on sub-boarding	10	10
Floor boards on fibreboard on sub-boarding	5	5
Separate joists to carry ceiling	5	5

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