POST-WAR BUILDING STUDIES
NO. 20

FIRE GRADING OF BUILDINGS

PART I
GENERAL PRINCIPLES AND STRUCTURAL PRECAUTIONS

BY A JOINT COMMITTEE
OF THE BUILDING RESEARCH BOARD
OF THE DEPARTMENT
OF SCIENTIFIC & INDUSTRIAL RESEARCH
AND OF THE FIRE OFFICES' COMMITTEE

LONDON: 1946
PUBLISHED FOR THE MINISTRY OF WORKS
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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 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 building.

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JOINT COMMITTEE ON FIRE GRADING OF BUILDINGS

To the Building Research Board and Fire Offices' Committee

GENTLEMEN, We, your Joint Committee on Fire Grading of Buildings,[1] beg leave to present the first part of our Report on the inquiry which we were appointed to undertake under the following terms of reference:

"To consider and make recommendations on the fire grading of buildings."

First, we would refer to the loss which the Committee suffered by the death in May 1943, of Mr. B. L. Hurst, our Chairman. Mr. Hurst was exceptionally well qualified for guiding the Committee's deliberations alike by his professional attainment and his personality. He was an eminent consulting engineer with long experience in the problems of the design of buildings: he had made a special study of the problem of fire grading both from the technical and the administrative standpoint. We set a very high value on his wide grasp of the problem, his wise counsel and judgment, and the work owes much to his sound guidance while it was being set on its course. The other members welcomed the appointment of Mr. C. Roland Woods, an original member of the Committee, as Chairman in place of Mr. Hurst. We regret also that we have to record the death in April 1945 of Mr. G. B. Sharples, who brought to bear on the problem many years of experience as an engineer and contractor.

The compilation of the Report was in the hands of our Secretary, Mr. R. C. Bevan of the Building Research Station, and we wish to express our appreciation of his services generally and in particular of his invaluable assistance in the difficult investigations arising out of our work.

We wish also to record the assistance we have received from Mr. W. W. Dewar and Mr. C. T. Webster of the Building Research Station, Mr. S. J. Docking of the Ministry of Home Security (Home Office), and Mr. J. A. Rogans of the Fire Offices' Committee; and finally our thanks for the facilities and help afforded by the Building Research Station and Fire Offices' Committee.

We held our first meeting on 15th October 1942, at which we agreed, on the proposal of our late Chairman, to the appointment of a small group of members to undertake the examination of the various problems involved and to report as necessary to the full Committee.

The Group in turn appointed small panels to consider certain of the major aspects, notably those of the height and cubic capacities of buildings and exposure hazard. The Group and the various Panels have held 42 meetings and the full Committee 6 meetings.

[1] This Committee was first appointed in 1938 by the Building Research Board and the Fire Offices' Committee, but on the outbreak of war the work was suspended until, in 1942, the Committee was reconstituted with an extended membership.

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The following Parts will be dealt with in later Publications:

PART II. FIRE FIGHTING EQUIPMENT IN BUILDINGS

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FIRE GRADING OF BUILDINGS

A REPORT BY A JOINT COMMITTEE OF THE BUILDING RESEARCH BOARD OF THE DEPARTMENT OF SCIENTIFIC AND INDUSTRIAL RESEARCH AND OF THE FIRE OFFICES' COMMITTEE

INTRODUCTION

1. The purpose of this Report is to review the underlying principles of fire protection in buildings, so far as existing knowledge permits, and to present the results in the form of recommendations.

It is not intended as a code for immediate application in practice, but as an exposition of the subject in the light of present-day knowledge, for the information of persons or bodies concerned in formulating rules for legal, insurance, or other purposes.

SCOPE OF REPORT

2. The term "fire grading," as applied to buildings, has not previously been defined, although it has been used to indicate the procedure of assigning to various elements of structure of a building, grades of fire resistance as defined in *British Standard* 476–1932, appropriate to the fire hazard arising from the occupancy and according to the height, floor area or cubic capacity of the building. In the wider sense it may be taken to mean the grading of fire precautions in buildings, *i.e.* the investigation and assigning of suitable fire precautions of any kind to attain an adequate standard of safety, according to the fire hazard of the building under consideration. We have interpreted our terms of reference in the latter sense, and have assumed accordingly, that they impose on us the obligation to examine the problems of fire precautions in buildings in a comprehensive manner, and to base on that examination recommendations which will be of value to any other body charged with the responsibility of formulating regulations or Codes of Practice for precautions against fire. We would emphasize that we attempt merely to set out the underlying principles of the subject. The formulation of rules and regulations, considered as they must be from the practical, legal, insurance, and other standpoints, is a matter for separate consideration, and bodies charged with that responsibility should each interpret the recommendations in the way most suited to their practical requirements.

3. The objects of fire precautions are to safeguard life and property. They are achieved by (a) preventing or reducing the number of outbreaks of fire; (b) limiting the development and spread of a fire in the event of an outbreak; and (c) providing for safe exit of occupants.

4. The importance of the first stage (a), *i.e.* of preventing or reducing the number of outbreaks of fire, cannot be over-emphasized. It includes, in general, such matters as the education of the public to avoid acts of carelessness likely to cause fire, and precautions against outbreaks in plant and machinery peculiar to industrial processes, etc. These subjects obviously open up a wide field for inquiry and recommendations, but although important and having a bearing on structural aspects, we have felt that any attempt by this Committee to deal with them in detail would represent a diversion from that part of the field with which we feel most directly concerned under our terms of reference. We appreciate that this aspect of the problem is one of primary concern, but, from such data as are available, it appears that a considerable proportion of all fires, both in this country and in America, are attributable to carelessness. It is doubtful whether this factor will ever be wholly eliminated, but we recommend that efforts should be

made through research and by other means to reduce the incidence of fires from this and other causes more susceptible to treatment, and to eliminate causes where possible. The fact remains, however, that because of the high proportion of fires due to carelessness, reliance must necessarily be placed on structural measures and fire fighting to minimize the danger from fire.

5. We have therefore confined our attention to the second and third stages, *i.e.* (b) limiting the development and spread of any fires that have started, and (c) the provision of adequate means of escape and other safeguards for the occupants of a building. Of these (b) alone has many aspects. It embraces steps to secure proper subdivision of large buildings by walls and floors of adequate fire resistance. It has to take into account the design of load-bearing members to provide this resistance to the effects of fire, and measures whereby the access of firemen is facilitated. It includes steps to minimize the risk of the spread of fire from one building or part of a building to another, whether they be contiguous or facing one another across a street or other open space. Such measures may be termed passive defence against fire.

6. It also embraces provision for the extinction of fires—the availability of fire extinguishing equipment, *e.g.* installation of sprinklers, provision of hand appliances, dry rising mains—measures which can conveniently be included under the head of active defence.

7. Any rational system of fire grading should provide a combination of active and passive defence in proper balance to meet the fire hazard in each case. Undue reliance on structural means might be uneconomic as adding unduly to building costs, especially if efficient means of extinguishing the fire can be depended upon. The same emphasis need not be laid on active defence if buildings are so planned internally and constructed as to reduce to a minimum the risk of the occurrence and spread of fire. The broad question is therefore one of striking the right balance between passive and active defence, and of adjusting the total precautions to the hazard so that the most rational and economic combination can be achieved.

SOURCES OF INFORMATION

8. In attempting to formulate our recommendations we have been handicapped by the lack of co-ordination of data on various aspects of the problem. We have had therefore to place considerable and perhaps undue reliance on personal experience. As a specific example of this lack of information, we would mention the absence of a co-ordinated body of fire statistics which would be so valuable for an inquiry such as the present. We understand that arrangements have now been made for the collection of statistical records. We shall have occasion, in several connections in the Report, to indicate how such data would have clarified the field of inquiry.

9. The last review of the position, in this country, on fire precautions in buildings was made by the Royal Commission on Fire Brigades and Fire Prevention which was appointed in 1923. In its report the Commission made a number of recommendations for action. Even so, few authorities have specifically addressed themselves to the question of diminution of danger from spread of fire. In America, on the other hand, the problem of fire protection is dealt with comprehensively in most up-to-date building codes.

10. Experimental investigations on fire resistance problems date back many years, and no review of the subject, however brief, would be complete without reference to the work of the British Fire Prevention Committee; but it is only within the past twenty years that work has been developing on lines which give us a direct lead. The work of the British Fire Prevention Committee suffered because, at that time, there was no generally accepted test procedure for obtaining comparable results. That need was met, in this country, by the issue, in 1932,

of the *British Standard* for Fire Resistance, etc., 476–1932. The Fire Offices' Committee then provided the expensive equipment needed for carrying out the standard test by building the Fire Testing Station at Elstree, where, by arrangement with the Fire Offices' Committee, numerous tests have been made by the Building Research Station. Other sources of information have been the reports of inquiries and regulations issued by various bodies, notable amongst which are the report of the Advisory Committee on the Amendment of the London Building Act for the Grading of Buildings and Building Materials; the regulations of the London County Council for the protection of structural steelwork; and the Ministry of Health Model Bye-laws dealing with the protection of steelwork. Another aspect of fire protection received attention in the publication of the Building Industries National Council on Means of Escape, which was followed in 1935 by the Home Office Manual on Safety Requirements in Theatres and other Places of Public Entertainment. It would be impracticable to summarize here the investigations and regulations which have been published both in this country and abroad dealing with the general problems, but we append a bibliography of some of the more important documents.

11. As noted above, American approach to the general problem of fire protection in buildings has been on a much wider scale, and we include in the bibliography Building Codes containing comprehensive regulations for fire precautions in buildings. We have been fortunate in having a first-hand account of American developments from Mr. Horatio Bond, the Chief Engineer of the National Fire Protection Association, while he was on a visit to this country. Special mention might be made here of a recent publication of the National Bureau of Standards which summarizes American knowledge of the subject of fire resistance.

12. The documents already mentioned refer to peace-time studies. War-time studies of fire problems have necessarily added greatly to our store of information and experience, and the results have been freely placed at our disposal by authorities concerned, notably the Ministry of Home Security, Ministry of Works, and the London County Council; they represent an invaluable contribution to our knowledge. There is, however, need for care in applying it to peace-time requirements. In war-time the possibility of simultaneous outbreaks of fire in numerous places necessitates greater reliance on structural protection than would be necessary or economic in peace-time when the chance of simultaneous outbreaks is small, and the attention of fire services can for the most part be confined to one fire. In assessing the results of war-time studies in terms of peace-time hazards due regard must be paid to this factor, and particularly to the fact that fire fighting was in certain cases restricted owing to lack of water. We have therefore exercised great care in applying this information to peace-time conditions.

COST OF FIRE PRECAUTIONS

13. Stringent precautions to prevent fire spread in buildings may add appreciably to the cost of building and, so far as material losses are concerned, the expense incurred should be in proportion to the reduction of fire loss that can be expected. From a national standpoint it would be uneconomic for the cost of precautions to exceed the expected saving except in certain cases, *e.g.* where the risk to life justifies a greater expenditure. This is an aspect of our problem on which there is urgent need for detailed statistical data.

APPLICATION OF RECOMMENDATIONS

14. Up to the outbreak of war there had been a slow but gradual development of fire precautions against normal peace-time hazards, with the result that very large conflagrations were in general avoided though fire losses were still considerable. It is important to bring about advances in practice, and in particular a proper balancing of the level of protection against degree of hazard for peace-time

purposes, which is our immediate concern. In so far as any improved standards would reduce war-time risks, they are of value for that purpose also, but it should be clearly understood that we have not been specifically concerned with war-time conditions.

15. Whilst our recommendations are intended as a basis for codes or regulations applicable to new buildings, our attention has inevitably been drawn to the many existing buildings which, by their situation, their manner of construction and their manner of use (frequently by a combination of these three factors), fall below the standards of safety which in the light of modern knowledge should be contemplated for the future, and, judged by the standards now proposed, must be held to constitute a serious fire risk. The difficulties of bringing such buildings up to the standards now contemplated would from many points of view be very considerable, particularly in the immediate post-war years, when there will be unprecedented demands on the building industry. In fact the probabilities are that any general action would be out of the question for some time to come. At the same time we think it right to call specific attention to the point in the interests of ensuring that such steps as are found practicable should be taken in all cases. We recognize that the greater proportion of fire loss occurs in old buildings and that it is unwise to repeat forms of construction which have proved unsatisfactory. Our recommendations are therefore intended to stimulate the use of constructions known to afford good fire protection.

16. We consider it fortunate that we should be reporting jointly to the Building Research Board and Fire Offices' Committee, for whilst the Board might be regarded as being concerned with the general public interest and the Committee with the arrangements of fire insurance companies, the two interests are in fact identical; and although the standards of the Fire Offices' Committee will presumably require greater attention to detailed needs of individual cases than recommendations for general application, great advantage would accrue from the adoption of a common basis of grading. We appreciate, however, that to meet the different needs it may well be necessary to make changes in detail of certain requirements.

17. Our Report is based on existing data and experience. Reference has already been made to difficulties arising from lack of data, and we hope that the Report will be of value not only for its primary purpose but also as an indication of the lines on which research should be pursued in future.

ARRANGEMENT OF REPORT

18. We shall present our Report in four Parts as follows:

Part I. General Principles and Structural Precautions.

Part II. Fire Fighting Equipment in Buildings, its amount and disposition (including special methods of fire extinguishment).

Part III. Means of escape and other aspects of personal safety.

Part IV. Chimneys and Flues.

Part I only is submitted herewith. It consists of two sections, the first of which applies to all classes of buildings except one- and two-storey houses, which are considered separately in Section II.

PART I. GENERAL PRINCIPLES AND STRUCTURAL PRECAUTIONS

GENERAL PRINCIPLES

FIRE HAZARD

19. To develop a rational system of fire precautions it is first necessary to obtain a clear picture of the objects to be achieved, and for this purpose it is necessary to analyse the various risks or "hazards" to which fire may give rise. Fire hazard may be subdivided under the heads of "internal hazard," or hazards which arise inside the building, and "external" or "exposure hazards" which arise as a result of fires in surrounding property. The internal hazard may be further subdivided into "personal hazard," the danger to the occupants of the building, and "damage hazard," the danger to the structure and contents of the building. There are, of course, many other possible ways of subdividing fire hazard, but for use in this Report we have adopted the following subdivision and nomenclature:

1. Personal hazard: the hazard to the occupants of the building.
2. Damage hazard: the hazard to the structure and contents.
3. Exposure hazard: the hazard due to fire from surrounding property.

20. We have placed personal hazard first, as it is concerned with safety of life, while damage hazard is concerned with property. Exposure hazard comes last as it concerns the building in relation to its surroundings. Though this order is logical, and has been followed in discussing the precautions to be taken in one- and two-storey dwellings (Part I, Section II), we have not found it convenient to follow the same order throughout our Report. Personal hazard and the precautions required to attain the necessary standard of safety (including means of escape) will be dealt with in Part III, whereas damage hazard and exposure hazard in buildings other than one- and two-storey dwellings are dealt with in Part I, Section I.

21. The relative importance of each of these hazards will vary according to the purpose for which the building is used, *i.e.* the "occupancy" of the building. It is customary to speak of buildings as being of a high, moderate, or low fire hazard, but in approaching the matter from first principles it is necessary to distinguish clearly from what standpoint the hazard is being considered.

22. A small building containing highly inflammable material may be described as a high hazard; a large building containing quantities of combustible material, *e.g.* a warehouse, would also be described as a high damage hazard even though actual outbreaks were likely to be few, because if a fire did occur the destruction of contents and structural damage might be considerable. Theatres, cinemas and other places of public assembly, even though their combustible content may be low, must be considered to present a high personal hazard primarily because of the large number of people involved. On the other hand, from this standpoint of safety of occupants, the warehouse, generally of high combustible content, would be a low personal hazard because of the few people likely to be in it.

FIRE PRECAUTIONS

23. The object of fire precautions is to minimize fire hazard. This can be achieved by precautions taken with the three following aims:

1. To reduce the number of outbreaks of fire.

2. To provide adequate facilities for the escape of the occupants, should an outbreak occur.
3. To minimize spread of fire both within the building and to near-by buildings.

24. We have decided that (1), the means of reducing the number of outbreaks of fire, does not fall within the scope of this Report. As to (2), it is unnecessary to emphasize the vital importance of the provision of means of escape, for some recent incidents in this country and abroad have resulted in serious loss of life. The planning, construction, and protection of means of escape is inseparable from fire defence and therefore forms an essential part of our studies. Finally, as to (3), spread of fire within a building and to near-by buildings can be prevented or minimized by one or other of two methods, or an appropriate combination of them: firstly, by suitable construction and internal planning of the building, having due regard to adjacent buildings, *i.e.* passive defence; and, secondly, by providing means of extinguishing fires, *i.e.* active defence.

FIRE PRECAUTIONS IN RELATION TO FIRE HAZARD

25. Precautions against fire and the fire hazard can be regarded as standing in much the same relation to each other as the strength of a structure and the loads it has to carry. A structural member is designed according to the load it has to carry plus a certain factor of safety. Similarly precautions against fire should be designed according to the fire hazard arising from the contents of the building and its structural character. Whilst the structural engineer is able to estimate with reasonable accuracy the physical loads he has to take into account, there is no means, other than in general terms, of expressing the fire hazard of a building. Recent work has enabled an approximate quantitative measurement to be made of the probable severity of fires in buildings, but this is but one factor of the many which go to make up the total hazard.

26. A rational scheme of fire grading should be so designed that the protection against the fire hazard would be by that combination of passive and active defence which is appropriate to the hazard involved, having due regard to practicability.

SECTION I. BUILDINGS OTHER THAN ONE- AND TWO-STOREY DWELLINGS

27. It would be impracticable to set out in a general report of this kind the precautions necessary to minimize the hazards individually for every possible type of occupancy. It is therefore desirable to classify or grade the various types of occupancy according to the fire hazards arising in each, and to set out the precautions necessary for these various grades.

We have found it necessary to approach the problem in two stages:

1. Grading on the basis of damage and exposure hazard.
2. Grading on the basis of personal hazard.

This distinction is called for because, not only do the factors which determine the hazards differ, but the protection in (1) is largely bound up with structural considerations, whereas in (2) it is more a matter of providing easy means of egress. As explained in paragraph 20, (2) will be dealt with in a later volume (Part III) of our Report. In the remainder of Section I of the present volume (Part I) we proceed to grade or classify occupancies on the basis of damage hazard;

next to consider requirements for fire resistance, cubic capacity, etc., in relation to damage hazard, and finally deal with the measures necessary to meet the probable exposure hazard. Provision for active defence will be dealt with in Part II.

GRADING OF OCCUPANCIES ACCORDING TO DAMAGE HAZARD

28. So far as the occupancy is concerned the damage hazard will depend largely on the amounts, natures, and distribution of the combustible materials, and it is therefore necessary to consider the grading in respect of each of these items.

Thus in a warehouse containing large quantities of combustible material the damage to the structure and the loss of contents would be much greater than in the case of an office block because of the greater quantity of combustible material in the former. The fire would be hotter and of longer duration.

The total weight of material is, however, not a sufficient criterion because in this respect the important factor is the total amount of heat that could be liberated. It is therefore necessary, because of the variation in the amount which can be liberated by the combustion of equal weights of different combustible materials, to use as a basis the total heat that can be liberated expressed in British Thermal Units per square foot of floor area.

FIRE LOAD AS A MEANS OF MEASURING DAMAGE HAZARD

29. By analogy with structural loads we have adopted the term "fire load" to describe the number of British Thermal Units which could be liberated per sq. ft. of floor area of a compartment by the combustion of the contents of the building and any combustible parts of the building itself. The fire load of a building has been used as the basis of our grading of occupancies. It may be determined simply by multiplying the weight of all combustible materials by their calorific values and dividing by the floor area under consideration. Thus, if a building or any part of a building contains 4000 lb. of combustible material of calorific value 8000 B.Th.U's./lb. over an area of 1000 sq. ft., the fire load would be:

$$\frac{4000 \times 8000}{1000} = 32{,}000 \text{ B.Th.U's./sq. ft.}$$

As the conception of fire load is new to this country, comprehensive data on the fire loads of various occupancies are not available, but investigations in this country and abroad provide a basis for a tentative grading of a number of common occupancies according to their fire load.

30. From data obtained from a number of sources relating to floor loads and combustible contents in buildings (including unpublished work of the Building Research Station) it appears that, in general, the fire load of residential buildings, hotels, hospitals, schools, offices, and similar occupancies, does not exceed 100,000 B.Th.U's./sq. ft.; the fire loads of shops and factories using combustible materials are usually greater than 100,000 B.Th.U's./sq. ft., whilst those of warehouses may range up to 1,000,000 B.Th.U's./sq. ft. or more.

31. These data suggest that a fire load of 100,000 B.Th.U's./sq. ft. would be a convenient limit for distinguishing between buildings of the first group and other occupancies such as factories, and accordingly we propose to describe these as occupancies of *low* fire loads. The distinction between shops and factories and storage buildings is not well defined; it has been necessary to use the relation which has been brought out by recent work in America and this country between the fire loads of occupancies and the grade of fire resistance of elements of structure

required to resist fires due to those fire loads. The relation is considered more fully in paragraphs 50–53, and for the present it must suffice to note that a fire in a building having a fire load not exceeding 100,000 B.Th.U's./sq. ft. is approximately equivalent to 1 hour exposure to the heating in the standard test[1]; a fire load between 100,000 and 200,000 B.Th.U's./sq. ft. is similarly equivalent to 2 hours of the standard test, etc. It is clear that a grading of occupancies closely related to the grades of structural fire resistance would be markedly advantageous, and we therefore propose the following grading of occupancies according to fire load:

(1) Occupancies of Low Fire Load are those in which the fire load does not exceed 100,000 B.Th.U's./sq. ft., *e.g.* generally domestic buildings, hotels, offices, etc.

(2) Occupancies of Moderate Fire Load are those in which the fire load exceeds 100,000 B.Th.U's/sq. ft. but does not exceed 200,000 B.Th.U's./sq. ft., *e.g.* generally trade and factory buildings.

(3) Occupancies of High Fire Load are those in which the fire load exceeds 200,000 B.Th.U's./sq. ft. but does not exceed 400,000 B.Th.U's./sq. ft., *e.g.* bulk storage buildings.

32. In occupancies in which the fire load consists chiefly of timber, paper, fabrics, *i.e.* materials having calorific values of the order of 8000 B.Th.U's./lb., these fire loads correspond to weights of about 12 lb./sq. ft., 12–25 lb./sq. ft. and 25–50 lb./sq. ft. respectively. For these materials the corresponding weights may be used instead of the values in B.Th.U's./sq. ft., but for materials having higher calorific values the above weights must be reduced in proportion to the calorific value of the materials concerned.

EFFECT OF NATURE AND DISTRIBUTION OF FIRE LOAD ON GRADING

Nature of Fire Load

33. The grading, as so far presented, is determined only by the amount and calorific value of the materials contained in the building. The same weights of different materials, which may be of the same calorific value, present considerable differences in general fire risk. For example, materials differ in their ease of ignition and the rate at which they burn; some materials may seriously hinder fire fighting because they emit noxious fumes especially when heated, or encourage the burning of other materials. Again, special risks may be found in a building because a process is introduced which involves application of heat to a combustible material, and there is then risk of frequent outbreaks of fire. It is therefore necessary to distinguish between occupancies which have a given numerical fire load but present no special risks, and those of the same numerical fire load but in which special risk arises from one cause or another. We propose to call the former normal risk fire loads and the latter abnormal risk fire loads, or for short "normal" and "abnormal," although the term "exceptional" has been considered as an alternative to "abnormal."

34. It is not easy to specify the factors which make an occupancy abnormal. Some are concerned with the materials involved, others relate to the process, but we give below a list of some of the factors which introduce high risks. They are separated into two groups, firstly those relating to materials, and secondly those concerned with processes. The list must be regarded merely as a guide and is not exhaustive.

35. *Materials.* So far as materials are concerned we are of opinion that the materials described as dangerous goods and explosives in the Memorandum of

[1] See Appendix VI.

the Departmental Committee (1933) of the Board of Trade on the Carriage of Dangerous Goods and Explosives in Ships should be taken as a basis on which to grade an occupancy as abnormal.

The substances in the list are divided into seven categories as follows, and presence of an appreciable quantity forming the contents or part of the contents of a building would indicate that the occupancy should be graded as abnormal risk.

1. Explosives.
2. Compressed "permanent," liquefied, and dissolved gases.
3. Substances which become dangerous by interaction with (a) water or (b) air. Substances falling under (a) also become dangerous by interaction with moisture in the air and to that extent can be included in (b).
4. All substances with flash point below 150° F.
5. Corrosive substances.
6. Poisonous substances.
7. Miscellaneous.
   A. Oxidizing agents.
   B. Substances liable to spontaneous combustion.
   C. Readily combustible solids.

In addition we consider it necessary to add two categories of substances which are likely to create special hazards of fire in buildings as follows:

8. Substances likely to spread fire by flowing from one part of a building to another:

   e.g. All oils, fats and waxes, rubber, lard, bitumen, pitch, etc.

9. Substances in such a form as to be readily ignitible:

   e.g. Wood shavings, paper, pieces of fabric, cotton, rags, fibre, down, flock, kapok and similar materials, flour, coal dusts, metal dusts, and other dusts and powders.

36. *Processes.* Use of one or other of the following typical processes might indicate that the occupancies should be graded as abnormal.

i. Those involving the application of heat, especially to combustible materials, *e.g.* gas singeing, ironing, drying rooms and compartments, heat treatment, creosoting, etc.
ii. Those involving the production of inflammable waste or dust, particularly when the latter arises through the use of disintegrators, grinders and such like reducing machines.
iii. Spray painting with inflammable or explosive liquids.
iv. Use of inflammable solvents.

37. We give in Appendix I a list of materials which fall within one or other of the groups indicated above, and in Appendix II a short list of occupancies in which the fire risk may be accentuated either by use or storage of such materials or by the nature of the process, and which therefore might fall within the abnormal class. These lists are by no means exhaustive, and again should be regarded as indicative of the nature of the material or occupancy which needs consideration. It is clear that the presence of small quantities of these materials, or the carrying on of a process on a small scale as an accessory to an otherwise normal occupancy, might not justify grading of the occupancy generally as abnormal. For instance, that part of the occupancy which is regarded as abnormal but has the same numerical fire load as the remainder may be adequately separated from the

remainder by fire resisting construction, and it would therefore be unreasonable to grade the whole occupancy as abnormal in such circumstances.

Distribution of Materials

38. The contents of a building are rarely disposed uniformly over the whole floor area. From the fire protection standpoint it would be undesirable to have all combustible material concentrated on a fraction of the floor area, as the average taken over the whole area would not give a true representation of the actual conditions, and the resulting effects on the structure immediately surrounding would be out of all proportion to those expected on the basis of average fire load. An investigation of the effects of fires suggests that when the fire load over any 10 ft. square of the floor area does not exceed twice the average and the contents are reasonably distributed in such units, the effects on the structure are not appreciably different from those found with a more uniform distribution. For example, if the contents on a floor in an occupancy of low fire load, *i.e.* not exceeding 100,000 B.Th.U's./sq. ft., were reasonably distributed in units which did not exceed 200,000 B.Th.U's./sq. ft. over any 10 ft. square, the effects on the structure would not differ appreciably from those due to a uniform distribution of 100,000 B.Th.U's./sq. ft.

39. In almost all occupancies not specifically designed for bulk storage, some part is used for storage. Thus, in offices storage space must be provided for records; in factories and shops reserve stocks, which may locally amount to a fire load of 1,000,000 B.Th.U's./sq. ft. or more, must be kept. If high concentrations of material are taken into account in computing the fire load the result may well be to force that occupancy into a higher classification than could be justified. Again, examination of occupancies which have suffered a complete burn-out indicate that high concentrations of this kind can cause severe damage to a building, but the effects are largely determined by the area over which the concentration of load is spread. If the area is of the order of 100 sq. ft., damage is often serious, and it is desirable that where there is likely to be need for storage space of this kind, it should be properly separated from the remainder by construction of an adequate grade of fire resistance and be limited in area, but the area may be omitted from the computation of fire load.

PROPOSED THREE GRADES OF OCCUPANCY

40. In order to take account of factors such as those just mentioned and provide greater tolerance in practice, it is thus desirable to qualify the grading set out in paragraph 31 as follows:

1. *Occupancies of Low Fire Load.* The fire load of an occupancy is described as low if it does not exceed an average of 100,000 B.Th.U's./sq. ft. of net floor area of any compartment, nor an average of 200,000 B.Th.U's./sq. ft. on limited isolated areas, provided that storage of combustible material necessary to the occupancy may be allowed to a limited extent if separated from the remainder and enclosed by fire resisting construction of an appropriate grade.

2. *Occupancies of Moderate Fire Load.* The fire load of an occupancy is described as moderate if it exceeds an average of 100,000 B.Th.U's./sq. ft. of net floor area of any compartment but does not exceed an average of 200,000 B.Th.U's./sq. ft., nor an average of 400,000 B.Th.U's./sq. ft. on limited isolated areas, provided that storage of combustible material necessary to the occupancy may be allowed to a limited extent if separated from the remainder and enclosed by fire resisting construction of an appropriate grade.

3. *Occupancies of High Fire Load.* The fire load of an occupancy is described as high if it exceeds an average of 200,000 B.Th.U's./sq. ft. of net floor area of any compartment but does not exceed an average of 400,000 B.Th.U's./sq. ft. of net floor area, nor an average of 800,000 B.Th.U's./sq. ft. on limited isolated areas.

APPLICATION OF GRADING OF OCCUPANCY

41. Where the intended occupancy is known it would be possible for a designer to determine, with the aid of tables of calorific values of materials, the numerical fire load of a building and in this way establish whether the occupancy falls into the low, moderate or high class. The "normality" of the occupancy may be determined in many instances by reference to the lists of materials and industries which are given in Appendices I and II respectively. For general design purposes, however, some readily available reference is desirable, and accordingly we indicate in Table 1 the general types of occupancy which fall into the respective grades.

42. Until more comprehensive data are available it will usually be necessary to adopt the grading given in Table 1, but we feel that, in the event of these data being used for codes or regulations, a designer should be given the option of producing evidence to show that an occupancy may be regraded, for in order to simplify the grading certain general kinds of occupancies have been included as a whole in one class. For example, all shops have been included as moderate fire load occupancies though there are certain shops, *e.g.* ironmongers, which could be graded as low fire load.

43. In presenting this grading of occupancies, we have been at pains to set out in reasonably full detail the conditions which normally pertain and need to be met by rules or regulations for one purpose or another. It is not suggested that such rules do or ought to follow our grading in detail: for, as commonly adopted in the past, a simple grading of occupancies into (1) domestic, (2) trade and commercial, and (3) warehouse, with appropriate subdivisions to cover the field, corresponds broadly to the three proposed groups. Some groups, however, include other occupancies, because the problem has been approached on the fundamental basis of fire load.

SPECIAL OCCUPANCIES

44. Whilst this grading will cover the greater proportion of occupancies, there remain a number which cannot conveniently be included in any one of the above groups. Firstly, there is a group of occupancies in which the fire load exceeds 400,000 B.Th.U's./sq. ft. There are, secondly, other occupancies which have fire loads falling within the limits of one or other of the above grades, but which require individual consideration because of the special risk, which in some cases may be very high, *e.g.* storage or manufacture of celluloid, but in others very low, *e.g.* churches and cathedrals. They will include, in addition to the above, such occupancies as underground car parks, flour mills, exhibition buildings, munition factories, tanneries, etc. (See paragraph 132.)

MIXED OCCUPANCIES

45. It has been considered desirable to defer consideration of mixed occupancies until Part III.

TABLE I. GRADING OF OCCUPANCIES BY FIRE LOAD

Note: This grading is based on the fire load, but it will be appreciated that this is not the only consideration to be taken into account (see paragraph 34), and it is recommended that technical advice should be taken when designing a building as to the grading of an occupancy.

	NORMAL	ABNORMAL (See paragraphs 33–36)
Examples of Occupancies of Low Fire Load	Flats, Offices, Restaurants, Hotels, Hospitals; Schools, Museums, Public Libraries, Institutional and Administrative Buildings	Factories and Workshops in which special risks arise through the presence or use of limited quantities of recognized hazardous materials and processes but which would otherwise be graded as "Low Fire Load—Normal."
	Factories and Workshops in which the materials and processes used are of a recognized non-hazardous nature, *i.e.* the materials involved are in general incombustible.	
	NORMAL	ABNORMAL (See paragraphs 33–36)
Examples of Occupancies of Moderate Fire Load	Retail Shops, *e.g.* Footwear, Clothing, Furniture, Groceries.	Retail Shops and Factories and Workshops in which special risks arise through the presence of large quantities of recognized hazardous materials or of recognized hazardous processes.
	Factories and Workshops generally.	
	NORMAL	ABNORMAL (See paragraphs 33–36)
Examples of Occupancies of High Fire Load	Warehouses and other buildings used for the storage in bulk of commodities of a recognized non-hazardous nature.*	Warehouses and other buildings used for the storage in bulk of commodities of a recognized hazardous nature.†

* Classified lists of materials have been prepared by the Fire Offices' Committee.

† Appendix I contains a number of examples of materials falling into this class.

B

GRADING OF BUILDINGS ACCORDING TO THE FIRE RESISTANCE[1] OF THEIR ELEMENTS

46. Having graded the hazards it is now necessary to consider the measures required to give the desired structural protection. The precautions include both passive and active defence measures. Fire fighting is of course assumed to be available in all cases, and we first consider the question of structural resistance to fire by grading buildings on the basis of the fire resistance of their elements in relation to the fire load.

47. We have taken, as a starting-point for grading, a form of construction so protected that the structural elements will resist a complete burn-out of the combustible contents without failure, and restrict spread of fire out of the compartment in which it starts, irrespective of any other means of dealing with the fire. We then consider other forms of construction giving lower levels of structural protection. It would be unduly onerous to require that every building should be so protected that it would resist a complete burn-out of its contents without collapse, for thereby we should not only eliminate certain forms of construction which have shown themselves to be of great utility, but also would largely increase the cost of building, and at the same time neglect the effect of other means of defence, *e.g.* fire fighting.

48. Taking therefore as a starting-point the provision of structural precautions to resist the effects of a complete burn-out, it is clear that different grades of fire resistance will suffice for that purpose according to the fire severity which is determined by the fire load. Thus in a building of high fire load the fire will be longer and hotter, *i.e.* of greater severity, than the fire in a building of low fire load.

49. The *British Standard* 476–1932 (see Appendix VI) enables various elements of structure to be graded according to the time for which they resist a certain standard fire severity determined by a time-temperature curve based on observations in actual fires. Thus an element of structure classified as offering Grade D fire resistance will successfully withstand the standard fire severity and comply with other conditions for 1 hour. If that element is incorporated in a building of which the fire load gives rise to a fire equivalent in severity to 1 hour exposure in the test, then the element should resist the building fire without failure. Thus if we can establish the relationship between the fire load of a building and the equivalent severity of the test fire expressed in hours of heating under test conditions, a means will be provided whereby buildings may be graded on the basis of their resistance to fire in relation to the fire load.

RELATION OF SEVERITY OF FIRES TO FIRE LOAD

50. The relation between standard heating and the temperatures and duration of fires in buildings due to the burning of various amounts of combustibles was first investigated in America. Several tests were carried out in which known weights of timber and paper were ignited and allowed to burn out in a specially built structure, the temperatures reached during the fire being recorded and plotted. It was then possible to match the curves so obtained with the corresponding curves of the various periods of the American standard test, and in this way to assess the equivalent severity of the building fire, *i.e.* in terms of hours of

[1] As in the past there has been a tendency to use the term " fire resistance " in a general way to describe a property of materials, we wish to emphasize that in this Report the term is used strictly in accordance with the definition given in the *British Standard* for Fire Resistance, etc., No. 476–1932 (see Appendix VI and Glossary).

standard heating. The results of these tests are given in Table 2, where the relation is expressed in terms of the weight per sq. ft. of the combustible material burned, which had calorific values between 7000 and 8000 B.Th.U's./lb., and the fire load in B.Th.U's./sq. ft. The standard heating is expressed in terms of hours of heating according to the standard American time-temperature curve, which is sufficiently close to the British Standard time-temperature curve to permit direct application of the results to the latter.

TABLE 2. EQUIVALENT SEVERITIES OF BUILDING FIRES (AMERICAN RESULTS)

COMBUSTIBLE CONTENT		EQUIVALENT SEVERITY OF FIRE IN HOURS OF STANDARD TEST
Weight lb./sq. ft.	Fire Load* B.Th.U's./sq. ft.	
10	80,000	1
15	120,000	1½
20	160,000	2
30	240,000	3
40	320,000	4½
50	380,000	6
60	432,000	7

* Calorific value of materials 7000–8000 B.Th.U's./lb.

51. If the calorific value of the materials differs appreciably from that of timber and paper, it would be necessary to adjust the weight of the combustible materials in Col. 1 to give the same fire load, *e.g.* the weight of a material having a calorific value of 16,000 B.Th.U's. to give an equivalent severity of 1 hour would be 5 lb./sq. ft.

52. Further data on the relation have been forthcoming from recent work carried out by the Building Research Station. The method adopted in the above tests of measuring the temperatures throughout the fires virtually precludes its application to actual building fires. The Building Research Station has recently developed a method whereby the temperatures reached in the walls, concrete columns, etc., of buildings during a fire can be estimated with sufficient accuracy long after the fire. It depends on the fact that brickwork mortar and concrete made with siliceous aggregates show certain colour and other changes which develop at fairly well defined temperatures. The temperatures so recorded were compared with the temperatures reached in a similar element when subjected to the standard heating for various times. In this way it was again possible to determine the equivalent severity of the building fire, *i.e.* in terms of the standard heating, and, from a knowledge of the fire load, to obtain the relation between the two quantities. The method, which is more fully described in Appendix IV, has the advantage that it can be applied to any building after a fire, and the effects of variations in materials which could not be dealt with in the American tests have been brought out. The results agree reasonably with the data of Table 2 for low fire loads, but indicate that the equivalent fire severities for higher fire loads are somewhat lower than those of Table 2. In arriving at the values which are given in Table 3, the relation between the conditions under test and the building fire has been fully considered. The relation is complex, and it would be beyond the scope of this Report to consider the matter in detail. We have, from a consideration of these two sets of data, adopted as a simple basis for our grading the equivalent severities given in Table 3.

TABLE 3. ASSUMED EQUIVALENT SEVERITIES OF BUILDING FIRES

FIRE LOAD B.Th.U's./sq. ft.	EQUIVALENT SEVERITY OF FIRE IN HOURS OF STANDARD TEST
Less than 100,000, *i.e.* low fire load	1
100,000–200,000, *i.e.* moderate fire load	2
200,000–400,000, *i.e.* high fire load	4

53. In arriving at the above figures we have considered the average results obtained for a number of occupancies, but it was clear that considerable variations could be expected from these average results. For example, there are instances where the severity of the fire would be greater than that expected from Table 3. Conversely there are instances where fire loads may give rise to fires which fall much below the equivalent severity expected, *e.g.* in stacks of waste paper which, owing to the close packing, cannot burn freely. These results are due essentially to variations in the rate of combustion, but there are not sufficient data to distinguish clearly between the degrees of resistance required. Again, the area of window through which heat can escape is a factor which may be important, for example, in basements with limited exit for heat.

54. Another factor which may have an important influence is the overall size of the building. It is clear that a very small area of high fire load may not contain sufficient heat to produce the effects expected; in a very large area, on the other hand, there may be concentration of heat at the centre of the area. There is no clear evidence to indicate how important this may be, but we consider that the data will fit the majority of cases, and general experience of the behaviour of buildings in blitz fires accords well with the results. These are points, however, which merit further research.

FULLY PROTECTED CONSTRUCTION

55. We conclude from these results that, in a building of low fire load, a fire resistance of 1 hour in the elements of structure would enable the building to withstand a complete burn-out without collapse. Similarly in a building of moderate fire load a fire resistance of 2 hours would be adequate, and for high fire loads 4 hours. We have thus obtained the necessary basis on which to formulate requirements for that grade of building which should resist a complete burn-out without failure and which we propose to call "fully protected construction."

FIRE RESISTANCE REQUIREMENTS FOR FULLY PROTECTED CONSTRUCTION

TYPES OF CONSTRUCTION

56. It is now possible to consider the fire resistance requirements which we propose for buildings of fully protected construction containing occupancies of low, moderate, or high fire loads, which, as indicated in Table 3, may give rise to fires of which the equivalent severities are 1, 2, and 4 hours respectively. To resist these equivalent severities, the elements of structure in the buildings would need to be of at least 1, 2, and 4 hours fire resistance. For convenience it is proposed to describe buildings with elements of structure having a fire resistance of not less than 4 hours as Type 1 construction. Buildings in which the elements of structure (excluding separating walls) have a fire resistance of not less than 2 hours are described as Type 2 construction and those in which the fire resistance is not less than 1 hour as Type 3 construction. For certain elements of structure

in each of these types a higher grade of resistance than is indicated by Table 3 is considered desirable. These changes relate to external, separating and division walls and are considered below. The proposed grades of fire resistance are summarized in Table 4.

EXTERNAL WALLS

57. Whilst in respect of external walls we have generally adhered to the minimum grades of fire resistance to resist a complete burn-out, it is recommended that in the case of external walls of 1 hour fire resistance, their use should be restricted to the walls of buildings of framed construction not exceeding 50 ft. in height. We regard the height limitation as a temporary measure until practical experience justifies its relaxation; the need for framed construction where 1 hour fire resistance is proposed is considered desirable on grounds of stability. In all other cases of low and moderate fire-load occupancies the fire resistance of the external walls should be at least 2 hours, and 4 hours in the case of occupancies of high fire load. The fire-resistance requirements of external walls in relation to exposure hazard are considered in paragraph 182.

SEPARATING AND DIVISION WALLS

58. We have considered it desirable, for the purpose of this Report, to avoid the use of the term "party wall" in view of the fact that the term is commonly used in different senses. Thus, in the Model Bye-laws of the Ministry of Health the term is applied to any wall designed to separate buildings in different ownership or occupation, whereas in the Rules of the Fire Offices' Committee it is applied without special regard to ownership or tenancy to any wall which, by reason of its physical characteristics, including permitted openings, is regarded as providing, in certain circumstances, a satisfactory separation between one fire risk and another. We have therefore used the term "Separating Wall" where reference is intended to a wall which separates buildings, and the term "Division Wall" where reference is intended to a wall which separates parts of the same building. For separating walls we propose that the fire resistance should be not less than 4 hours irrespective of considerations of the fire load. This is necessary because the occupancy on each side of the wall may vary from time to time. On the other hand, the fire resistance of the division wall can be related to the fire load, so that in the case of an occupancy of high fire load the fire resistance should be not less than 4 hours, and for an occupancy of moderate fire load not less than 2 hours. On this principle the fire resistance of the division wall in a building of low fire load need be only 1 hour, but we consider that on account of the special function which the wall has to perform the fire resistance of 2 hours should be regarded as a minimum, even for occupancies of low fire load, to ensure full protection in all cases. It must be appreciated, however, that in considering separating and division walls there may be factors which justify the use of walls thicker than those which would comply with the proposed standards.

USE OF COMBUSTIBLE MATERIALS

59. Although a relatively high standard of fire resistance may be obtained with certain combustible elements of structure by taking special precautions, their incorporation in buildings of Types 1–3 construction would defeat the object aimed at in those types. For example, a timber joist floor may be protected by means of pugging and special ceilings so that it affords 1 hour or more fire resistance under test conditions, but fire on the upper surface may ignite the structure and lead to a complete burn-out. We therefore consider that all structural parts of buildings of Types 1–3 construction which are required to have a specified grade of fire resistance should be of incombustible material, except that timber doors which attain the required grade may be used.

TABLE 4. MINIMUM FIRE RESISTANCE (IN HOURS) OF ELEMENTS OF STRUCTURE IN BUILDINGS REGARDED AS FULLY PROTECTED

TYPE OF CONSTRUCTION	MINIMUM FIRE RESISTANCE IN HOURS								
	WALLS				COLUMNS AND BEAMS SUPPORTING				STAIRCASES, FLOORS AND FLAT ROOFS
	External	Separating	Division	Other Fire-Resisting or Load-Bearing Walls	External Walls	Division Walls	Other Fire-Resisting or Load-Bearing Walls	Floors	
Type 1	4	4	4	4	4	4	4	4	4
Type 2	2	4	2	2	2	2	2	2	2
Type 3	1* 2†	4	2	1	1* 2†	2	1	1	1

* In buildings of framed construction when height does not exceed 50 ft.
† Minimum for load-bearing walls, and other walls exceeding 50 ft. in height.

FIRE RESISTANCE REQUIREMENTS IN BUILDINGS OF FULLY PROTECTED CONSTRUCTION CONTAINING SPECIAL OCCUPANCIES

FIRE LOADS GREATER THAN 400,000 B.TH.U'S./SQ. FT.

60. In principle a fire resistance of more than 4 hours would be necessary in the structural elements of buildings where the fire load exceeds 400,000 B.Th.U's./sq. ft. if risk of collapse from a complete burn-out is to be expected. This fire load, which corresponds to about 50 lb./sq. ft. of combustible material of calorific value of 8000 B.Th.U's./lb. may, of course, easily be exceeded in bulk storage warehouses. For such buildings 6 hours protection could be used if desired, but in general it would probably be unduly onerous in some respects to require a 6 hours fire resistance, bearing in mind the fact that under normal conditions supplementary protection is available in the form of fire fighting, etc. It seems, therefore, that whilst it may be left to the discretion of a designer to adopt a 6 hours fire resisting construction, it would be preferable not to make this standard obligatory except for separating and division walls, but rather to require 4 hours fire resistance in the elements on the understanding that the construction should not be regarded as fully protected.

OTHER SPECIAL OCCUPANCIES

61. In occupancies which are graded as "special" because of the presence of highly inflammable materials, *e.g.* celluloid, the actual fire severity corresponding to any given fire load may, as indicated in paragraph 53, exceed the equivalent severity quoted in Table 3. The least fire resistance required may be determined solely from the estimated fire load, but special precautions may be necessary in other respects and each occupancy should be considered individually. It may, however, not be possible from the structural standpoint to describe the construction so determined as fully protected.

FIRE RESISTANCE REQUIREMENTS FOR OTHER TYPES OF CONSTRUCTION

62. Strictly speaking, the principle of determining the required fire resistance of structures by relation to the fire load should apply only to those buildings in which the elements of structure are designed to resist complete burn-out, *i.e.* fully protected constructions.

In the lesser fire resistant types of construction it is possible that collapse of upper floors, with their combustible contents, would result in the structural elements of a lower storey being subjected to a greater severity of fire than would be indicated by the fire load. We feel, however, that the fire load grading may be used equally well in respect of buildings of types of construction other than fully fire resistant types, because we propose later to recommend certain restrictions in their areas and heights, which, taken in conjunction with the greater ease with which fire in smaller buildings can be fought and brought under control, tends to guard against the risk of spread of fire by failure of the structural elements.

63. Having established requirements for buildings to resist a complete burn-out, it is now necessary to consider those types in which the elements have lesser grades of fire resistance in relation to the fire load of the contents. For that purpose we envisage the following additional gradings:

a. *Partially Protected Construction*, in which the elements of structure have a defined fire resistance but are not capable of resisting a complete burn-out without other means of defence. Thus if a building of Type 2 construction contains an occupancy of high fire load there would be risk of collapse which may, however, be avoided by fire fighting. The structure is therefore described as partially protected in relation to that fire load. Type 3 construction used for moderate or high fire loads would similarly be partially protected in relation to moderate or high fire loads. We introduce an additional type, namely Type 4, in which the minimum fire resistance of the elements of structure (excluding external, separating and division walls) is ½ hour. It should be noted that a construction can be regarded as fully or partially protected only in relation to the fire load of the occupancy.

b. *Externally Protected Construction*, in which the internal construction, except separating and division walls, has no specified fire resistance, *i.e.* does not attain ½ hour firer esistance but which has external incombustible masonry walls of at least 2 hours fire resistance. The common types of building which would be included in this category are structures with external walls of load-bearing masonry having either timber joist floors and timber roofs or unprotected internal steel framework. We suggest this type should be called Type 5.

c. *Unprotected Incombustible Construction*, representing the lowest standard of incombustible construction from the fire resistance standpoint. None of the elements of construction, again excepting separating and division walls, are required to have a specified degree of fire resistance, but should be of incombustible material. It includes, for example, the shed type building with unprotected steel frame with asbestos cement or metal sheeting as the external covering. We shall refer in future to this type as Type 6 construction.

d. *Combustible Construction*, in which the external walls, floors, and roofs are of combustible materials and which will be referred to as Type 7.

64. In all cases the fire resistance of separating walls should be not less than 4 hours and that of division walls should be sufficient to afford full protection according to fire load as shown in Table 4 with a minimum of 2 hours.

65. We attach no special significance to the actual system of numbering adopted to identify the types of construction. As indicated in paragraph 74, the grading provides for three main groups and it would therefore be possible to include the seven standards under three main headings, *e.g.* Types 1–4 as Types 1a, b, c, and d in that they all have specified grades of resistance; Type 5 might then be described as Type 2, and Types 6 and 7 as Types 3a and 3b respectively. Again, Type 1 construction might be referred to as 4 hour Type, Type 2 as 2 hour Type, etc. The respective advantages of the various nomenclatures is open to considerable discussion, but we have adopted a straightforward system in this Report.

FIRE RESISTANCE OF ROOFS OF BUILDINGS OF GRADED TYPES OF CONSTRUCTION

66. From the fire protection standpoint the functions of the roof of a building are in many respects similar to those of the external walls. The roof like the walls should afford the necessary protection against entry of fire into the building, an aspect which will be dealt with under the general question of exposure hazards (paragraph 186). Hitherto it has been the practice, chiefly on account of structural considerations, to accept a much lower standard of resistance against internal fire for the roof than was required for the walls. It has, in fact, been suggested that early collapse of the roof or part of the roof is advantageous for fire fighting. This opinion is, however, not held generally as applying to all cases, but there is agreement that it holds in several important cases, *e.g.* in certain buildings containing hazardous storage, or where hazardous conditions exist, it is an

advantage from the point of view of fire protection and to facilitate fire fighting for the roof or part of the roof to collapse at an early stage during a fire. Examples of this are:

a. *Fire Protection.* (1) Theatre stages where the light glazed lantern allows vertical escape of smoke and fire and reduces risk of lateral spread to the auditorium. (2) Cellulose spraying inside factories, where light glazing may have a similar effect.

b. *Fire Fighting.* Wooden-floored buildings used for granaries, wool warehouses and the like, where it is sometimes impossible owing to dense smoke for firemen to locate a fire until it has burned through the roof and ventilated the building.

67. In other cases the contrary holds. For example, unprotected steelwork in roofs may, through expansion or collapse, cause collapse of the upper parts of the external walls into which the trusses are tied, adding to the danger of spread to adjoining buildings and to the dangers of fire fighting. Again, wooden roofs add to the fire risk by contributing to the severity of the fire. On balance the correct view would seem to be that, with the exception of those parts specifically designed to vent an internal fire, a roof should preferably be adequately fire resistant to internal fire. The degree to which a roof can be made fire resistant may be largely governed by practical considerations, as, apart from concrete roofs, conventional design methods lead to the use of members of small section, thereby conducing to low standards of resistance. To demand, generally, a standard of resistance in roof construction comparable with that required of the walls would exclude many of the roofs commonly in use in this country. Whilst both pitched and flat roofs, whether of timber, steel, or concrete, could be made fire resisting, the flat roof presents certain advantages from the standpoint of fire protection. It can more easily be made resistant to exposure; it affords good facilities for fire fighting and escape; and where there is a ceiling the additional hazard presented by the space between a pitched roof and ceiling is eliminated.

RECOMMENDED GRADES

68. In order to conform with the general standard of construction of buildings of Types 1, 2, and 3 the roofs should be wholly of incombustible material and of a specified grade of fire resistance. Consideration has been given to the question whether the same fire resistance is desirable in the roof as in the floors. The criterion of temperature rise on the unexposed surface called for in testing floors is, of course, an essential feature if adequate resistance to spread of fire is required, but a higher temperature rise on the outer surface of the roof slab is not so important. We felt, however, that it would not be desirable generally to recommend, in the case of buildings of Types 1, 2, and 3 construction, roofs which have a lesser grade of fire resistance than the floors.

69. Of various types of roofs, concrete roofs alone would normally comply with those conditions, but we appreciate that, for certain buildings, where large unobstructed floor areas are required, truss roofs are essential. It is then almost impossible to protect the members so as to attain any high grade of fire resistance, though in certain cases it might be possible to provide a ceiling which could afford the necessary protection, *e.g.* in the Canadian Building Code a ceiling 1 in. thick of plaster on metal lath properly fixed is accepted as affording protection equivalent to 1 hour fire resistance.

70. Such methods would be practicable in certain cases only, but as the unprotected steel truss roof has been in common use for many years we feel it would be unreasonable to exclude its use in buildings which otherwise are of fire resisting construction. Although there have been cases where damage has been caused by failure of unprotected roof trusses, we consider that their use might be

permitted in buildings otherwise of fire resisting construction, containing occupancies of low or moderate fire loads not exceeding 100 ft. high, where it is impracticable to provide protection to roof trusses; where any other system of roof construction is unsuitable, and other parts of the roof construction are of incombustible material. A building with such a roof would not, of course, be regarded as fully protected.

71. Roofs of buildings of Types 4, 5, and 7 construction may be of timber, but in the case of Type 4 construction we should regard it desirable to require ceiling protection giving a fire resistance of ½ hour. Roofs of buildings of Type 6 construction should be wholly of incombustible material except as provided in paragraph 139, but need not be of a specified grade of fire resistance.

FIRE RESISTANCE REQUIREMENTS IN BASEMENTS (INCLUDING SUB-BASEMENTS)

72. In all grades of occupancy the basement of a building presents certain special risks. It is frequently used for storage, and the severity of the fire is increased by the absence of openings through which part of the heat can escape. Fire fighting will be seriously hindered by smoke, etc. Moreover, should the columns in a basement fail by fire, the whole of the superstructure would be affected. Accordingly, we consider a higher grade of fire resistance to be desirable in basements of partially and fully protected buildings, and propose that a minimum of 2 hours should be adopted in all occupancies of low fire load, and 4 hours in the case of moderate fire loads, but we should not regard it as essential to require more than 4 hours fire resistance for occupancies of high fire loads. Other special requirements for basements, *e.g.* provision of smoke extracts and special staircases, will be dealt with in paragraphs 150 and 151.

APPLICATION OF GRADINGS

73. It will be noted that we have adopted standards determined by the resistance to fire of whole elements of structure without referring to the nature or type of materials used. In this way we provide for the use of any system of construction, should it attain the required standard, but it must be appreciated that their suitability for general use will depend on other factors not necessarily taken into account by the fire resistance requirements, *e.g.* stability, durability, etc.

74. The system of grading which we have recommended provides for a gradually decreasing resistance to fire. In Types 1, 2, 3, and 4 all the structural elements have specified grades of fire resistance; in Type 5 only the external walls, main dividing and load-bearing walls are graded; and in Types 6 and 7 only the division and separating walls are required to resist fire. The suitability of any one type for a particular use will depend on circumstances, but the choice will be largely determined by the limitations which we recommend later in respect of height, area, cubic capacity, separation, etc.

75. A summary of the grading recommendations giving the fire resistance required of the various elements of structure for each type of construction is set out in Table 5.

Note: The following is an indication of the kind of occupancy for which the various types of construction as listed in Table 5 might be used. It must be appreciated that the list is merely illustrative, as, subject to limits of height, floor area, etc., any type of construction may be used for any occupancy:

Types 1, 2, and 3—Large warehouses, large shops or factories, blocks of offices and flats respectively.

Types 4 and 5—Small shops or factories; apartment houses.

Type 6—Single-storey factories, garages. Type 7—Timber houses, factories, etc.

TABLE 5. PROPOSED MINIMUM FIRE RESISTANCE REQUIREMENTS FOR GRADED TYPES OF CONSTRUCTION, WITH EXAMPLES OF CONSTRUCTION CONFORMING TO TYPE

GRADING OF CONSTRUCTION	MINIMUM FIRE RESISTANCE (IN HOURS) OF MAIN ELEMENTS OF STRUCTURE: WALLS, AND COLUMNS AND BEAMS SUPPORTING WALLS				MINIMUM FIRE RESISTANCE (IN HOURS) OF MAIN ELEMENTS OF STRUCTURE	EXAMPLES OF CONSTRUCTION‡ CONFORMING TO TYPE (See Appendix VI)
	External	Separating	Division	Other F.R. or Load-Bearing	FLOORS AND ROOFS AND COLUMNS AND BEAMS SUPPORTING FLOORS AND ROOFS	
Type 1. Incombustible, fire resisting construction. To be considered fully protected in relation to High Fire Loads, *e.g.* large warehouses.	4	4	4	4	4	Steel frame with 2½ in. concrete protection. Walls of brickwork 9 in. thick. Filler joist or reinforced concrete floors 6 in. thick or hollow tile floor of equivalent fire resistance.
Type 2. Incombustible fire resisting construction. To be considered fully protected in relation to Moderate Fire Loads, *e.g.* shops and factories.	2	4	2 4†	2	2	As above but 2 in. protection to steel, filler joist or reinforced concrete floors 5 in. thick or hollow tile or other floors of equivalent fire resistance.
Type 3. Incombustible fire resisting construction. To be considered fully protected in relation to Low Fire Loads only, *e.g.* office and residential buildings.	2*	4	2 4†	1	1	As above but 1 in. protection to steel or 1 in. cement mortar on expanded metal. Concrete floors 3½ in. thick, or equivalent.
Type 4. Fire resisting construction but not necessarily incombustible and may therefore include timber floors and timber roof construction. Partially protected only in relation to all fire loads.	2*	4	2 4†	1	½	Load-bearing brick walls. Timber floors and roof, protected by plaster ceilings on expanded metal. Fire retardant roof covering.

TABLE 5 (*contd.*). PROPOSED MINIMUM FIRE RESISTANCE REQUIREMENTS FOR GRADED TYPES OF CONSTRUCTION, WITH EXAMPLES OF CONSTRUCTION CONFORMING TO TYPE

GRADING OF CONSTRUCTION	MINIMUM FIRE RESISTANCE (IN HOURS) OF MAIN ELEMENTS OF STRUCTURE					EXAMPLES OF CONSTRUCTION‡. CONFORMING TO TYPE (See Appendix VI)
	WALLS, AND COLUMNS AND BEAMS SUPPORTING WALLS *				FLOORS AND ROOFS AND COLUMNS AND BEAMS SUPPORTING FLOORS AND ROOFS	
	External	Separating	Division	Other F.R. or Load-Bearing		
Type 5. Externally protected construction. Fire resisting incombustible external walls, non fire resisting internal construction.	2	4	2 4†	1	—	Load-bearing brick walls. Timber floors and roofs. Fire retardant roof covering.
Type 6. Non fire resisting construction. Incombustible.	—	4	2 4†	—	—	Unprotected steel frame and roof trusses, clad externally with corrugated sheeting.
Type 7. Non fire resisting construction. Combustible.	—	4	2 4†	—	—	Timber framed and/or clad external walls. Timber floors and roof with fire retardant covering.

* 1 hour for low fire load occupancies in framed buildings not exceeding 50 ft. in height.

† If occupancy is of high fire load.

‡ It should be appreciated that these are intended as examples only, and any other form of construction which complies with the recommended grades could be used.

See paragraph 72 for fire resistances required in basements.

REQUIREMENTS FOR GRADED TYPES

SUBDIVISION OF BUILDINGS

76. By the use of elements of structure of an appropriate grade of fire resistance, it is possible largely to eliminate the risk of the structure collapsing under the effects of fire, but the full benefits are not obtained if the contents are destroyed, because their value often greatly exceeds that of the building itself. There have been many fires in which the building has suffered relatively slight damage yet the whole of the contents have been destroyed. Some loss of contents is inevitable, but the extent of the loss can be reduced if the building is so constructed that the fire is confined to a small section. If the building is so large that there is risk of extensive loss, it should be divided up so that the amount of contents directly exposed to fire is limited. A second reason for this subdivision arises from considerations of exposure hazard. A fire in large undivided buildings situated in a normal congested urban or suburban area would create a considerable conflagration risk.

77. As it is not practicable to limit the size of a building, we propose that buildings which exceed a certain size should, if necessary, be suitably divided into division or compartments. A division of a building is defined as a part of a buildin separated from the remainder by fire resisting walls carried vertically throughout the height of the building and, if necessary, above the roof, whilst a compartment is a part of a building or of a division of a building separated from the remainder by fire resisting walls and floors. Any openings in the walls and floors would need protection by doors of a grade of fire resistance sufficient to ensure that proper separation is obtained. In that connection it may be noted here that whilst a fire resisting door may be classified as being of 2 hours fire resistance, it may not offer the same resistance to penetration of heat as a wall of that grade, because the standard test does not require the temperature rise criteria to be applied to iron and steel doors and shutters. Accordingly openings where protection is required should be limited in size and number. (See paragraph 142.)

A building may contain one or more divisions, and a building or a division may contain one or more compartments. It is clear that a building can only be separated into compartments if the floors are of an adequate grade of fire resistance; the ordinary timber-floored building can only be divided into divisions.

HEIGHT, FLOOR AREA,[1] AND CUBIC CAPACITY OF BUILDINGS, DIVISIONS, AND COMPARTMENTS

78. The two main objects of regulating the size of a building or any division or compartment of a building are to limit the extent of the loss of contents and to reduce the risk of an outbreak of fire developing into a conflagration. It is clear that the smaller the volume exposed to a fire in any one section the smaller will be the loss, and where very valuable goods of a combustible nature are stored the volume should be reduced to a minimum. To that extent therefore the building should be subdivided into the smallest possible sections. On the other hand, an industry may require extensive areas for proper functioning, *e.g.* several acres may be necessary for production lines; departmental stores require large areas for display of goods; and to avoid hindrance to trade it is very necessary to strike a balance between the fire hazard and the needs of the trade or industry.

79. Restriction of the cubic capacity of a building does not necessarily introduce a limit to its height, and it is desirable to limit the height of buildings in which

[1] This relates to area in any one storey or compartment according to the type of construction (see Glossary).

there is risk of collapse under the effects of fire, for reliance must be placed largely on external fire fighting. We have therefore to consider what restrictions should be imposed both in respect of height and overall size. In our approach to the problem we shall consider first the nature of the existing regulations both in this country and abroad.

EXISTING REQUIREMENTS.

80. The limitations on the size of buildings found in the Model Bye-laws relate only to buildings permitted to be constructed, in part, of combustible materials and are of limited interest for present purposes. Otherwise in this country it appears that restrictions which relate to buildings used for trade, manufacture or warehousing, are imposed only by the London County Council and the City of Liverpool. In general these restrictions do not apply to the entire building, which can be of any extent, except as regards height, provided it is subdivided internally into divisions or compartments.

81. Since 1855 there has been a restriction on the cubical extent of buildings or divisions of buildings in the London Building Acts. The present Act provides that the cubical extent of any building or division of a building used for trade or warehouse purposes must not exceed 250,000 cu. ft. without the consent of the Council.

82. Consent for additional cubical extent is normally granted provided, *inter alia*, that the building be throughout of fire resisting construction, and the Council may also require the building to be fitted with an approved sprinkler system.[1] Even so the floor area of each compartment may be limited to 40,000 sq. ft. in the case of a multi-storey trade or industrial occupancy, and to 20,000 sq. ft. if the building is intended for bulk storage. It is also the Council's present practice to require for fire fighting purposes in the case of trade buildings, terraces for fire fighting on storeys having their floor level at a height of 80 ft. or more above pavement level.

83. The Act also requires that no building of any class may, without consent, exceed 100 ft. in height, or 80 ft. if the floor area of the building exceeds 10,000 sq. ft., the distance being measured from ground level to the highest part of the topmost storey. The Council is, however, empowered to consent to a greater height, but the number of buildings exceeding 100 ft. in height in London is relatively small: it is worthy of note, however, that considerations besides those relating to fire risk have influenced the height restrictions which it seemed necessary to impose.

84. In 1938 the Council published additional regulations to allow protection to steel-work other than that required in the bye-laws, to be provided according to a required grade of fire resistance appropriate to buildings of various sizes and occupancies.

85. The City of Liverpool (Liverpool Corporation Act 1921, Part XVIII Fire Prevention) imposes restrictions whereby the height and floor area of warehouse buildings are controlled, and the limits given in Table 6 may not be exceeded without the consent of the Fire Prevention Committee.

TABLE 6

HEIGHT	MAXIMUM FLOOR AREA
Not exceeding 21 ft.	7500 sq. ft.
,, ,, 30 ft.	6000 sq. ft.
Exceeding 30 ft.	4000 sq. ft.

[1] Wherever sprinkler systems are mentioned in this Report only automatic systems are implied.

No warehouse may be built to a height exceeding 75 ft. without the consent of the Committee.

86. Of the corresponding limitations in other countries, mention must be made of those in force or proposed in the various building codes issued in the United States of America and in the recently published Canadian Code.

87. All the codes are similar in that the restrictions are based on height, number of storeys and floor area, and are determined both by occupancy and type of construction. With few exceptions as to locality, no restrictions are imposed on height or floor area if the construction is of the "fireproof" type, *i.e.* the elements of construction have a resistance of at least 4 hours. The maximum permissible height for buildings of lower grades of fire resistance is about 80 ft. in all codes, falling to 20 ft.–30 ft. for buildings corresponding to our Types 6 and 7. Floor areas are also restricted. The codes generally permit greater areas according to the number of streets on which the building abuts. Thus the area permitted when the building abuts on one street may be increased by about 20 per cent if the building abuts on two streets, and by about 50 per cent if on three or more streets, though in one code a 100 per cent increase is permissible if the building abuts on four streets. The apparent justification for these increases is the greater access for fire fighting.

88. In addition to these allowances, it appears to be the universal practice to permit a further 100 per cent increase in area if an approved automatic sprinkler system is installed. However, in certain classes of occupancies, *e.g.* those used for manufacture, sale, or storage of combustible goods, garages, etc., it is laid down in some codes that sprinkler equipment should be installed in every building when the area exceeds a certain figure. For example, the Building Code recommended by the National Board of Fire Underwriters of the United States of America requires sprinklers for all buildings over two storeys in height used for the manufacture, sale, or storage of combustible goods which exceed 10,000 sq. ft. in floor area when of "fireproof" construction or 7500 sq. ft. if the construction is not "fireproof."

89. The American codes do not generally permit floor areas to be increased in proportion as the height of the buildings falls below the maximum, a concession which, as already noted, follows automatically in the London County Council requirements on account of limitation by cubic capacity. The Uniform Building Code does, however, grant certain increased areas when the number of storeys falls below the maximum.

90. The comprehensive treatment of this aspect of fire precautions in buildings is a notable feature of these American codes, but the unlimited unsprinklered areas do not take advantage of the fact that the fire loss can be largely reduced by proper subdivision. It may be argued that, as very large areas are permitted where they are essential for the industry, any generally applicable restriction would need to be the subject of frequent relaxation, unless it were sufficiently generous to permit the erection of buildings with undivided floor areas of some hundreds of thousands of square feet. Under these conditions, however, it would have little practical significance, but the additional requirements outlined above, applicable to buildings which contain the more hazardous occupancies, often ensure that sprinkler equipment is installed in most of the buildings concerned.

BUILDINGS IN THIS COUNTRY ERECTED WITHOUT LIMITATION OF SIZE

91. In view of the fact that generally in this country there have been no obligatory restrictions on the capacity and heights of buildings, we have thought it desirable to obtain information as to the size of certain large buildings which have been erected. Our inquiries are by no means complete, but we have noted several buildings which can be regarded almost as of "unlimited" capacity. One multi-

storey industrial building covers an area of 240,000 sq. ft. at ground floor level rising to a maximum height of about 60 ft. The whole building forms a single compartment by virtue of the several wells and open staircases. Another large building used for trade purposes consists of 6 storeys each greater than 40,000 sq. ft. in area, and each communicating by means of an open staircase. Both buildings are of fire resisting construction and fully equipped with sprinklers and fire fighting equipment. The former is well spaced from other buildings but the latter has been erected in the centre of a large city, surrounded at no great distance by smaller buildings many of which are probably of "excess cube" judged on the basis of the London Building Act.

92. Another building of two storeys covers an area of about 240,000 sq. ft. in a central situation in a moderate size town, whilst single-storey buildings covering many acres used for manufacture or storage are by no means uncommon.

93. Few buildings exceeding 120 ft. in height have been erected in this country and up to the present there seems to have been no general demand for greater heights in industrial buildings. Buildings exceeding this height usually contain office type occupancies; one reaches over 200 ft. in height, and we understand that others of equal or greater height are proposed in the same city.

FACTORS INFLUENCING THE LIMITS OF SIZE

94. A proper solution of the problem of size limitation requires extensive statistical data on the fire losses in buildings in relation to the many factors which contribute to fire safety. Such data are not available, but we have agreed that limitation in certain types of buildings is necessary on the grounds of fire safety, while accepting the fact that, where very large undivided areas are essential for the trade or industry, they should be permitted if special provision be made in respect of fire precautions. Our subsequent observations and proposals relate mainly to the general classes of buildings likely to be erected in urban areas, but we emphasize that larger areas are not by any means excluded, and a section on such structures is included in the Report (paragraph 126).

95. The size and height which can be permitted in any building will depend on numerous factors, *e.g.* type of occupancy, construction. A comprehensive analysis of all the factors is outside the scope of this Report, but we give a brief survey of the bearing which the more important have on the problem. These are (a) type of construction; (b) nature of occupancy; (c) fire extinguishment.

a. *Type of Construction*

96. A building or division of not more than 250,000 cu. ft. may, if in one occupation, be erected in London with brick walls and timber floors without special precautions. An outbreak of fire in a warehouse building of this class of construction would often lead to complete loss of contents. We understand that this size represents approximately the maximum volume of fire which would reasonably be tolerated from the fire fighting standpoint. The hazard in a building of that extent, provided with separation of adequate fire resistance between each storey, would be much reduced and greater latitude could therefore be allowed, because the capacity of each compartment, assuming the division consisted of 5 storeys, would be only 50,000 cu. ft.

97. If 250,000 cu. ft. is regarded as the limit for a brick wall and timber floor building, then in a building with each storey properly separated from the storey above and below by construction of sufficient fire resistance to prevent spread, the same capacity could be permitted in each storey, for the total volume of fire would be no greater than in the former case. In general, therefore, the more fire resisting the construction of the building in relation to its fire load, the greater can be its permissible size, for even though it may not be capable of resisting a complete

burn-out, it may be possible to extinguish the fire or at least control it so that the structure retains its efficiency as a barrier. It should be borne in mind that the timber floor adds appreciably to the combustible content.

98. However, even with the building of fully protected construction, *i.e.* one which will resist a complete burn-out of the contents, there is reached ultimately a limit when the size of a compartment attains proportions with which fire fighting cannot satisfactorily cope, especially as regards the danger of spread to other buildings, unless special requirements are laid down in respect of separation from surrounding buildings. The risk of excessive loss must also be taken into account.

b. *Nature of Occupancy*

99. The risk of conflagration developing from an outbreak of fire is largely influenced by the severity of the initial fire, and this in turn depends on the fire load of the occupancy, *e.g.* a fire in a bulk storage warehouse of high fire load presents a greater risk than an outbreak in a block of offices of low fire load. Again, in an occupancy containing highly inflammable material, *i.e.* an abnormal occupancy, there are likely to be more frequent outbreaks and the fire may spread more rapidly and thus present a greater exposure hazard than in one of the same numerical fire load, but in which outbreaks are likely to be less frequent, *i.e.* a normal occupancy. To take account of this greater risk the maximum permissible size should be less than that considered desirable for the normal occupancy. Again, in certain classes of residential property the loss of accommodation resulting from fire might have to be considered, even though the size of the building does not present a high risk from the fire standpoint.

c. *Fire Extinguishment*

100. The last factor which we shall consider in detail concerns the extinguishment of fires. It can conveniently be dealt with under three heads:

Efficacy of fire fighting.

Accessibility of building for fire fighting.

Sprinkler installations and internal fire fighting equipment.

101. *Efficacy of Fire Fighting.* It has necessarily been assumed in formulating our recommendations that throughout the country there will be an effective standard of fire fighting. There will certainly be differences, *e.g.* as between urban and rural areas, but the fire problem is primarily an urban problem, and we have assumed that it will be the aim to provide reasonably uniform fire fighting facilities in urban areas.

102. *Accessibility of Building.* For our present purpose we have adopted the term "accessibility of a building" to describe that part of its perimeter which abuts on streets, or other open space directly accessible from a street, from which fire fighting can adequately be carried on. The need for accessibility is not so marked or necessary in the case of smaller buildings, but a fire in a large compartment may be almost impossible to attack and become beyond control if, for example, the sole accessible frontage were on the leeward side to which the flames were being blown.

103. In London requirements in this connection are, we understand, among the considerations taken into account in dealing with buildings of the trade or warehouse class exceeding 250,000 cu. ft. in extent in any division. The basis adopted is to require that, in any such building where there are more than two storeys above the ground storey, a portion of the site shall abut upon a thoroughfare or thoroughfares not less than 40 ft. wide, or the building set back so as to provide that distance, the portion being proportional to the cubical extent of the building.

104. The practice is also to require that at least one stairease, *e.g.* a fire tower, designed for fire fighting purposes and having access to all floors and the roof, shall be provided where the cubical extent of any division exceeds 1,000,000 cu. ft. It is understood that each case is considered independently and that no hard and fast rules are laid down, for special cases arise which, if judged strictly on that basis, would result in undue hardship. Nevertheless, because it is possible to deal separately with each instance, the principle appears to have given good results. In American codes, on the other hand, accessibility is noted merely by the number of streets on which the building abuts.

105. *Sprinklers and Fire Fighting Equipment.* General experience and the statistical data that we have been able to obtain show that automatic sprinkler systems properly installed and maintained, and provided with adequate water supply, have a very high degree of efficiency. A sprinkler system markedly reduces the risk of an outbreak of fire developing into a large fire, and it is therefore possible, where such systems are installed, to allow buildings of much greater extent than would otherwise be suitable. Nevertheless there is a limit which even then should not be exceeded, for, despite the very high efficiency of such systems, occasional failures do occur, such as those due to the human element, *e.g.* turning off sprinkler valves during repair work or during a fire, lack of appreciation of function of apparatus, or improper stacking of goods, and safety then depends on structural considerations and manual fire fighting.

106. As already noted, in American codes unlimited floor areas without sprinkler systems are permitted in buildings in which main elements have a fire resistance of at least 4 hours, but we believe that in practice few modern buildings of large area are not sprinklered, as it is certainly a matter of economy to install a sprinkler system. There are certain occupancies, *e.g.* those involving highly inflammable contents, in which a system is essential. In other occupancies little advantage may be gained. Again, conditions may vary so greatly in occupancies which are apparently of similar business that sprinklers may be necessary in one but not vital in the other. There is some evidence, not sufficient to be conclusive, that in modern buildings of fire resisting construction serious fires are infrequent. If it could be shown that fire losses are very small in buildings of fully protected construction which are not sprinklered, greater tolerance could be allowed in the maximum sizes of buildings before it becomes necessary to install a sprinkler system—apart, of course, from the incentive to do so that is provided by reduction of insurance premium, a factor with which we are not concerned. Taking account of all the factors and statistical data which are available, the general practice in American codes of permitting an increase of 100 per cent in the allowable areas if sprinklers are introduced appears reasonable.

107. Whilst hand equipment suitable for use by occupants should be regarded as necessary in all buildings, in high buildings or buildings covering large floor areas additional equipment for use by trained personnel or fire service is required. Dry risers, hydrants, etc., should be installed in such buildings as part of their normal equipment, for the difficulties of conveying water through hoses, etc., up to considerable heights and through large areas markedly reduces the efficiency of fire fighting. This will be dealt with in Part II of the Report.

108. We now proceed to our recommendations as regards height, floor area, and cubic capacity.

RECOMMENDATIONS FOR MAXIMUM HEIGHTS

109. Our recommendations for the maximum heights to which buildings of various types of construction should be erected are given in Tables 7a, b, and c. We have taken the height of a building as the vertical distance from the highest level of the street, way, or yard, etc., adjoining the building, to the underside of

the ceiling of the topmost storey; or, if all or part of the topmost storey is in the roof space, to the highest point of the underside of the ceiling, or, if there is no ceiling, to the underside of the tie beam or collar beam. We propose no restrictions on the heights of buildings in which individual compartments are designed to resist a complete burn-out except in the case of abnormal occupancies. This applies, if the occupancy is of low fire load, to Types 1, 2, and 3 construction; if of moderate fire load, to Types 1 and 2; and of high fire load to Type 1 only. In the case of buildings containing abnormal occupancies we propose a limit of 100 ft.

110. Fires in buildings of these types can be fought from inside the building, as there should be no risk of collapse, but to facilitate fire fighting in high buildings we propose certain special requirements in respect of equipment and facilities for internal attack in buildings which exceed 100 ft. in height. In arriving at this figure we have taken into account the fact that turntable ladders used by the fire services enable water to be projected direct on to a fire at heights up to 100 ft. above street level.

111. For other types of construction height limitations are necessary, having due regard to risk of collapse and the resulting hindrance to fire fighting within the building.

112. For buildings in which the elements of structure are one grade lower than that required to resist a complete burn-out we propose a maximum height of 75 ft., except that, in the case of a building of Type 4 construction containing a low fire load occupancy, we regard 50 ft. as the desirable maximum, as we propose that combustible floors of ½ hour fire resistance could be used. Proportionately lesser heights are proposed for buildings in which the construction is not of specified fire resistance, but as buildings of Type 6 construction are limited to one storey, no height limit is proposed unless the building contains an occupancy of high fire load. We do not suggest rigid adherence to these figures, as it is commonly found in practice that a tolerance of, say, 5 feet is of great assistance to designers.

RECOMMENDATIONS FOR FLOOR AREAS AND CUBIC CAPACITIES

Basis of Limitation of Capacity

113. In considering limitation of capacity the first problem is the basis to adopt—whether by cubic capacity or floor area. The London Building Act adopts cubical extent as a basis, whilst Liverpool and all American codes limit floor area. The restriction in the London Building Act automatically permits greater floor areas as the height of the building falls below the maximum, and as there is no doubt that height adds greatly to the difficulties of fire fighting, the increased floor areas for lesser heights are justifiable on that ground. This basis of measurement appears both reasonable and proper when applied to multi-storey buildings not of fire resisting construction, but in the case of fully protected buildings, wherein each compartment is separated from others by construction adequate to resist a complete burn-out, the size of the individual compartment should be considered. It is not logical, except in a building used for bulk storage, to apply the "cube" basis only to compartments, because a compartment of minimum height but large floor area would be disadvantageous from a fire fighting standpoint as compared with one which is of greater cubic capacity on account of its greater height, even though the floor area may be slightly smaller. In such cases limitation by floor area is more appropriate.

114. We have therefore used floor area as the basis for limitation in the case of fully protected buildings where additional storey height may be provided for purposes of light and air. In our Tables, however, we have included for ease of reference the cubic capacity of the compartment, based on a storey height of 12 ft. 6 in., which appears to be a reasonable average. In storage buildings of

high fire load, however, full use may be made of the storey height for storage purposes, and therefore cubic capacity should also be limited. Strictly this is not necessary because the total amount of combustible material contained in any compartment is limited by the fire load, but as rigid adherence to the fire load principle may not be practicable at the present time, we have decided to retain the well-known basis of "cubic capacity."

Accessibility

115. The next aspect which must be considered is that of accessibility. The methods adopted in London and in the American codes have been studied from the standpoint of general application; other methods have also been considered; but all of them present difficulties in application in one respect or another. The American system has the advantage of simplicity, but it does not ensure that a certain proportion of the perimeter abuts on a street, nor does it control the width of the street in relation to height of the building, though other regulations may provide a reasonable standard in respect of these factors. The problem is one that impinges on town planning, and a study of it in relation to proposals for limiting the amount of site cover, and in respect of the ratio of height of building to the width of the street, has not been possible.

116. We suggest that every building and division of a building should have a portion of its perimeter abutting upon a street or streets. In buildings whose capacity exceeds 100,000 cu. ft. the portion so abutting should be not less than 8 ft. for every 1000 sq. ft. of floor area of the building or division, and the street or streets should be not less than 40 ft. in width, or the building set back from the street boundary a sufficient distance to meet this requirement. We should regard an open space of the required width as equivalent to a street if it were on the same plot as the building and had direct access of sufficient width and height for mobile fire fighting appliances from a street.

In buildings of Type 1, 2, 3, or 4 construction every compartment should have direct access from a staircase leading directly from a street (or equivalent open space) or from not less than two other compartments at the same floor level, in order to assist fire fighting within the building.

117. In respect of the height-width ratio, it is proposed that for fire fighting purposes the external wall of a building exceeding 40 ft. in height which abuts on a street or streets as suggested above should, where necessary, be set back so as to fall within a plane inclined at an angle of not more than $63\frac{1}{2}^\circ$ to the horizontal from the building line on the opposite side of the street at pavement level. In buildings other than those of low normal fire load, set-backs should be provided at heights above 100 ft. in the form of terraces about 6 ft. wide at each floor level for access of firemen. These terraces should have suitable access from staircases.

Maximum Floor Areas and Cubic Capacities

118. The maximum floor areas and cubic capacities given in Tables 7a, b and c and 8 are those which we consider satisfactory for normal urban and suburban development. Each of Tables 7a, b, and c is divided into two parts. The first part relates to buildings of fully protected construction where the limits apply to the compartments; the second part relates to other types of construction which are limited by cubic capacity of the division. Single-storey buildings are dealt with in Table 8. In arriving at the figures for fully protected buildings we have relied largely on the limits adopted by the London County Council, but have agreed to an increase in the maximum floor area of any compartment of buildings of fully protected construction when the accessibility is at least three-quarters of the perimeter. The perimeter, for the latter purpose, may be deemed to be the sum of the sides of a square having an area equal to the floor area of the compartment.

119. No limit of floor area is proposed for fully protected buildings containing occupancies of low normal fire load.

120. The most serious fires in peace-time in recent years have occurred in warehouse buildings of brick walls and timber floors (corresponding to our Type 5) built to the 250,000 cu. ft. limit. We have therefore concluded that for moderate and high fire loads this limit is excessive, and we have considerably reduced it for buildings of that type of construction except those containing occupancies of low fire loads. Buildings of Type 7, *i.e.* timber construction, containing low fire loads are restricted to 36,000 cu. ft., but a greater capacity is proposed for single-storey buildings in this type of construction. All such buildings should, of course, be subject to special requirements in respect of exposure hazard.

Sprinkler Systems (Automatic)

121. *Multi-Storey Buildings.* Buildings, divisions or compartments of buildings of fully protected construction, other than low normal fire load occupancy, should be generally equipped with an approved sprinkler system where the area on any one floor exceeds 10,000 sq. ft. In buildings not of fully protected construction, other than of low normal fire load occupancy, we propose that the cubic capacities given for unsprinklered buildings may be doubled where sprinklers are installed, and no unsprinklered floor area should exceed 7500 sq. ft.

Single-Storey Buildings. Except in the case of occupancies of low fire loads where unlimited areas are considered permissible, the cubic capacities given in Table 8 may be doubled when sprinkler systems are installed.

Automatic Fire Alarms

122. It will be noted from Tables 7a, b, and c that buildings having a floor area, on any one floor, up to 10,000 sq. ft. may be erected in fully protected construction without a sprinkler installation. Consideration of the risk involved suggests that in cases where the cubic capacity of the whole building exceeds 250,000 cu. ft., but where the area on any floor does not exceed 10,000 sq. ft., the building should be equipped with an approved automatic fire alarm system so arranged as to call the public fire service or other efficient brigade in the event of fire. This recommendation need not apply to buildings falling within the above limits but which, nevertheless, are equipped with an approved automatic sprinkler installation. The cubic capacity may be calculated on the basis of a storey height of 12 ft. 6 in., except in the case of high fire load occupancies.

Compartments at Heights of more than 100 ft.

123. Considerations of fire fighting make it desirable to impose a further limitation on the cubical capacity of compartments the floors of which are at a height of more than 100 ft., and we suggest that the maximum floor area of a compartment of which the floor is at a height of more than 100 ft. from the street level should not exceed one-half the maximum values given in Table 7. This limitation need not apply to occupancies of low (normal) fire load.

Buildings of all Categories in which the Area on any one Floor exceeds 10,000 sq. ft.

124. As in the case of buildings exceeding 100 ft. in height, fire fighting difficulties increase considerably with extensive floor areas; fire hoses may have to be laid several hundred feet, etc., and we therefore propose that special provision be made for fire fighting in all divisions and buildings where the floor area exceeds 10,000 sq. ft., and where any portion of the division or building is more than 100 ft. from a street frontage or open space. These items will be considered in Part II.

Sub-basements (i.e. Basements lower than the Storey immediately below the Ground Storey) or Compartments of a Sub-basement

125. The increased difficulties of fire fighting below ground level, especially in sub-basements, makes a further limitation on the maximum floor area and cubic capacity desirable, and we suggest that the floor area and cubic capacity of a sub-basement in a fully protected building, when not sprinklered, should not exceed 5000 sq. ft. or 62,500 cu. ft.; when sprinklered, the figures may be increased to 20,000 sq. ft. and 250,000 cu. ft. In respect of other types of construction the maximum floor area and cubic capacity of the sub-basement should not exceed 3750 sq. ft. and 47,000 cu. ft. respectively when unsprinklered, or double these values when sprinklered. These limits need not apply to special types of buildings such as safe deposits, banks, strong-rooms and other storage for valuables.

BUILDINGS EXCEEDING RECOMMENDED LIMITS

126. We regard the heights, floor areas, and cubic capacities given in Tables 7 and 8 as the maximum appropriate under normal conditions, and we consider that the needs of the vast majority of occupiers will be met. There may, however, be special cases where the needs of trade require greater areas, *e.g.* production lines; or, in rare cases, greater heights may be essential.

127. Consideration has therefore been given to those cases where, for special reasons, there may be a demand for larger compartments than those recommended. One such special case is that of newspaper printing works in which large printing machines, requiring considerable height of storey and floor area, are installed and in which the provision of compartment walls might seriously handicap expeditious printing and publication. Another such case might be a department store building (and possibly other large retail establishments) where there may be a desire, on the part of the owner, to connect storeys by means of a central well for the purpose of display.

128. Accordingly some departure from the recommended limits of floor area and cubical capacity set out in the Tables might be made in circumstances where the siting, access, planning, and other relevant factors justify such action. The occupancies involved will usually be of low or moderate fire load; only in the most exceptional cases should deviations be allowed where the fire load is high. We feel it is undesirable to lay down any hard and fast rules for such special cases because there will almost invariably be ancillary factors which would require large buildings to be considered separately on their merits, but in order to assist in dealing with such cases we suggest the following general principles should be taken into account:

a. That where very large areas are allowed the number of storeys should be kept to a minimum.

b. That where heights in excess of those set out in Tables 7 and 8 are necessary the floor areas of the compartments should be kept as small as possible.

c. That the maximum possible degree of isolation from other buildings should be provided.

d. That any part of the building used for storage, or for an abnormal occupancy or any portion offering a higher risk than the general risk, should be separated from the remainder of the building by incombustible fire resisting construction of appropriate grade (but in no case less than 1 hour).

e. That if of more than one storey, the building should be of fully protected construction according to the fire load.

f. That if single storey only, the building should be of incombustible construction and the use of combustible material reduced to a minimum.

g. Suitable automatic sprinkler equipment should be installed where desirable.

h. The recommendations for fire fighting equipment applicable to floor areas greater than 10,000 sq. ft. area or heights in excess of 100 ft. should apply. Special water supplies should be installed where necessary.

j. Such additional reasonable safeguards as will reduce the fire risk in the special circumstances of each particular case should be required.

k. The staff of the occupier to include trained personnel always to be available so as to attack a fire immediately and to ensure the satisfactory maintenance and operation of all fire protection apparatus and fire extinguishing equipment.

DEPARTMENT STORES AND LARGE RETAIL SHOPS

129. For the purpose of providing a particular example of a case where some increase over the maximum floor areas and cubical capacities set out in the Tables might be specially desirable, one of us (Mr. Digby Solomon) has proposed in discussion that the department store or large retail shop might be considered where, as mentioned above, there may be a desire on the part of the owner to have a central well in his building combining a number of floors. Such a practice exists in many provincial towns but is only permissible to a limited extent in London, on account of the limitations imposed on the size of compartments. In the provincial towns, however, the position is unsatisfactory in that many of the buildings are of unprotected or combustible construction and considerably exceed the limits of size now recommended for such types.

130. The large retail shop or department store presents a special life hazard by reason of the large quantities of combustible materials hung on fittings distributed about the floor area, and the provision of open wells in such a building of very large cubic extent in which considerable numbers of the public might be expected to congregate, involves considerable risk. The question of risk to life is not dealt with in this part of our Report. On the basis of the fire load grading we should regard the department store as an occupancy of moderate fire load (normal) and where each storey is separated from others the limits in Table 7 (b) would apply; *i.e.* if the building is of Type 2 construction and the accessibility at least three-quarters the floor area of the compartment may be 60,000 sq. ft.

131. Our colleague's proposals for the store incorporating a central well are as follows:

i. Where provision is made for cutting off the well from each floor by means of automatically operated double steel rolling shutters: the area of each floor exclusive of the well not to exceed 40,000 sq. ft.; the height of the part containing the well not to exceed 80 ft. or 4 storeys above the ground storey; special sprinkler and fire extinguishing equipment to be provided.

ii. Where the well is not cut off by shutters: the area of the ground floor not to exceed 40,000 sq. ft.; the *combined* area of the upper floors, excluding the well, not to exceed 60,000 sq. ft.; the height and number of storeys in the well being limited, and special fire extinguishing equipment provided as in (i) above.

The gross floor areas proposed represent a considerable increase over the limits in Table 7 (b) but, nevertheless, particularly with the idea in view that it will probably accelerate the replacement of unsatisfactory buildings referred to above by buildings of somewhat similar layout but of fully protected construction, the majority[1] of us is of the opinion that buildings such as are proposed by our colleague might be permitted, subject in either case to the provision of some

[1] Mr. Durant and Mr. Thorowgood do not subscribe to this view and have submitted observations giving their reasons (see page 86).

TABLE 7A. MAXIMUM HEIGHTS, FLOOR AREAS AND CUBIC CAPACITIES OF COMPARTMENTS OF BUILDINGS OF TYPES 1, 2, OR 3 CONSTRUCTION CONTAINING LOW FIRE LOADS (*e.g.* FLATS, OFFICES, ETC.)

TYPE OF CONSTRUCTION	HEIGHT FEET	MINIMUM ACCESSIBILITY OF BUILDING OR DIVISION	FLOOR AREA OF COMPARTMENT SQ. FT.		CUBIC CAPACITY OF COMPARTMENT		NOTES
			Normal Occupancy	Abnormal Occupancy	Normal Occupancy	Abnormal Occupancy	
1. (4 hours)	No Limit (Normal) 100 ft.* (Abnormal)	Three-quarters of Perimeter	No Limit	60,000	No Limit	500,000	1. Cubic capacity to be measured on maximum storey height of 12 ft. 6 in. 2. It is recommended that buildings containing abnormal occupancies should be sprinklered throughout where compartment floor area exceeds 10,000 sq. ft. Where for some reason sprinklers cannot be installed the floor area should not exceed half the areas quoted. 3. See paragraphs 123 and 125 for special precautions when building exceeds 100 ft. in height or 10,000 sq. ft. floor area.
2. (2 hours) or 3. (1 hour)		8 ft. per 1000 sq. ft. of Floor Area	No Limit	40,000	No Limit	750,000	

MAXIMUM HEIGHTS AND CUBIC CAPACITIES OF BUILDINGS OR DIVISIONS OF TYPES 4, 5, AND 7 CONSTRUCTION CONTAINING LOW FIRE LOADS

TYPE OF CONSTRUCTION	HEIGHT FEET*	MINIMUM ACCESSIBILITY	CUBIC CAPACITY OF BUILDING OR DIVISION		
			NORMAL OCCUPANCY	ABNORMAL OCCUPANCY	
				Sprinklered	Not Sprinklered
4. (½ hour)	50	8 ft. per 1000 sq. ft. of Floor Area of Division	500,000†	250,000	125,000
5.	50	,,	250,000†	200,000	100,000
7.	30	,,	36,000 (2 storeys only)	See Table 8	

* Subject to tolerance of +5 ft.　　† If in one occupation.

TABLE 7B. MAXIMUM HEIGHTS, FLOOR AREAS AND CUBIC CAPACITIES OF COMPARTMENTS OF BUILDINGS OF TYPES 1 OR 2 CONSTRUCTION CONTAINING MODERATE FIRE LOADS (*e.g.* SHOPS, FACTORIES, ETC.)
NORMAL AND ABNORMAL OCCUPANCIES

TYPE OF CONSTRUCTION	HEIGHT FEET	MINIMUM ACCESSIBILITY OF BUILDING OR DIVISION	FLOOR AREA OF COMPARTMENT	CUBIC CAPACITY OF COMPARTMENT	NOTES
1. (4 hours) or 2. (2 hours)	No Limit (Normal) 100 ft.* (Abnormal)	Three-quarters of Perimeter	60,000	750,000	1. Cubic capacity to be measured on maximum storey height of 12 ft. 6 in. 2. It is recommended that buildings should be sprinklered throughout where compartment floor area exceeds 10,000 sq. ft. Where for some reason sprinklers cannot be installed the floor area should not exceed half the floor areas quoted. 3. See paragraphs 123 and 125 for special precautions when building exceeds 100 ft. in height or 10,000 sq. ft. floor area.
		8 ft. per 1000 sq. ft. of Floor Area	40,000	500,000	

MAXIMUM HEIGHTS AND CUBIC CAPACITIES OF BUILDINGS OR DIVISIONS OF TYPES 3, 4, AND 5 CONSTRUCTION CONTAINING MODERATE FIRE LOADS

TYPE OF CONSTRUCTION	HEIGHT FEET*	MINIMUM ACCESSIBILITY	CUBIC CAPACITY OF BUILDING OR DIVISION			
			NORMAL OCCUPANCY		ABNORMAL OCCUPANCY	
			Sprinklered	Not Sprinklered	Sprinklered	Not Sprinklered
3. (1 hour)	75	8 ft. per 1000 sq. ft. of Floor Area of Division	500,000	250,000†	250,000	125,000
4. (½ hour)	50	,,	250,000	125,000	150,000	75,000
5.	40	,,	100,000	50,000	100,000	50,000

* Subject to tolerance of +5 ft.

† Maximum area on any one floor not to exceed 7500 sq. ft.

TABLE 7C. MAXIMUM HEIGHTS, FLOOR AREAS AND CUBIC CAPACITIES OF COMPARTMENTS OF BUILDINGS OF TYPE 1 CONSTRUCTION CONTAINING HIGH FIRE LOADS (*e.g.* WAREHOUSES, ETC.) NORMAL AND ABNORMAL OCCUPANCIES

TYPE OF CONSTRUCTION	HEIGHT FEET	MINIMUM ACCESSIBILITY OF BUILDING OR DIVISION	FLOOR AREA OF COMPARTMENT	CUBIC CAPACITY OF COMPARTMENT	NOTES
1. (4 hours)	No Limit (Normal) 100 ft.* (Abnormal)	Threequarters of Perimeter	60,000	750,000	1. Cubic capacity to be measured on full storey height. 2. It is recommended that buildings should be sprinklered throughout when compartment floor area exceeds 10,000 sq. ft. Where for some reason sprinklers cannot be installed the floor areas should not exceed half the values quoted. 3. See paragraphs 123 and 125 for special precautions when building exceeds 100 ft. in height or 10,000 sq. ft. floor area.
		8 ft. per 1000 sq. ft. of Floor Area	40,000	500,000	

MAXIMUM HEIGHTS AND CUBIC CAPACITIES OF BUILDINGS AND DIVISIONS OF TYPES 2, 3, 4, AND 5 CONSTRUCTION CONTAINING HIGH FIRE LOADS

TYPE OF CONSTRUCTION	HEIGHT FEET*	MINIMUM ACCESSIBILITY	CUBIC CAPACITY OF BUILDING OR DIVISION			
			NORMAL OCCUPANCY		ABNORMAL OCCUPANCY	
			Sprinklered	Not Sprinklered	Sprinklered	Not Sprinklered
2. (2 hours)	75	8 ft. per 1000 sq. ft. of Floor Area of Division	500,000	250,000†	250,000	125,000
3. (1 hour)	50	,,	250,000	125,000	150,000	75,000
4. (½ hour)	50	,,	100,000	50,000	100,000	50,000
5.	25	,,	50,000	25,000	50,000	25,000

* Heights subject to tolerance of +5 ft.

† Maximum area on any one floor not to exceed 7500 sq. ft.

TABLE 8. SINGLE STOREY BUILDINGS (IN ONE OCCUPATION AND WITHOUT BASEMENTS)

MAXIMUM CUBIC CAPACITIES OF BUILDINGS, DIVISIONS, AND COMPARTMENTS OF BUILDINGS

Types of construction lying above the thick line are regarded as fully protected in relation to the particular occupancies

<table>
<tr><th rowspan="3">TYPE OF CONSTRUCTION</th><th colspan="6">MAXIMUM CUBIC CAPACITY OF BUILDING OR DIVISION†</th></tr>
<tr><th colspan="2">LOW FIRE LOAD OCCUPANCIES</th><th colspan="2">MODERATE FIRE LOAD OCCUPANCIES</th><th colspan="2">HIGH FIRE LOAD OCCUPANCIES</th></tr>
<tr><th>Normal</th><th>Abnormal</th><th>Normal</th><th>Abnormal</th><th>Normal</th><th>Abnormal</th></tr>
<tr><td>1</td><td rowspan="3">No Limit</td><td rowspan="3">1,000,000 (No Limit if Sprinklered)</td><td colspan="2" rowspan="2">1,000,000</td><td colspan="2">1,000,000</td></tr>
<tr><td>2</td><td colspan="2">1,000,000</td></tr>
<tr><td>3</td><td colspan="2">500,000</td><td colspan="2">500,000</td></tr>
<tr><td>4</td><td rowspan="2">500,000</td><td rowspan="2">250,000</td><td colspan="2" rowspan="2">250,000</td><td colspan="2" rowspan="2">250,000</td></tr>
<tr><td>5</td></tr>
<tr><td>6</td><td>500,000</td><td>250,000</td><td colspan="2">250,000</td><td colspan="2">250,000*</td></tr>
<tr><td>7</td><td>75,000</td><td>50,000</td><td>75,000*</td><td>50,000*</td><td>50,000*</td><td>40,000*</td></tr>
</table>

† Cubic capacity to be based on height of 12 ft. 6 in., excepting occupancies of high fire load, and buildings of Type 7 construction.

* Height of building not to exceed 25 ft.

See paragraph 124 for buildings of greater cubic capacity.

Cubic capacities may be doubled if buildings are "sprinklered," except as indicated.

automatic means of venting the fire from the top of the well, to the general qualification as regards separate consideration for each case, and to the introduction of such safeguards (a–k above) as might be appropriate in each case.

SPECIAL OCCUPANCIES

132. Similar general principles apply in considering special occupancies, but because each requires separate consideration we have thought it advisable to defer their study until a later stage, more particularly so as the fire risk is often accompanied by other risks, and it is not possible to make recommendations unless these other factors are taken into account. Thus in considering the underground car park, account must be taken of the risk arising from a possible explosion of petrol vapour and of the toxic risk from petrol vapour and exhaust fumes.

CHANGES OF OCCUPANCY

133. The suggestions for the classification of occupancies and grading of buildings have been developed largely on the basis that the precautions should be related to the hazard. There may as a result arise certain difficulties created by changes in occupancy, but it appears to us that the problems will be analogous to those arising from changes of occupancy in relation to loadings assumed in structural design. It is clear that the difficulties could be met by requiring buildings to be constructed of the highest grade of fire resistance, but such a requirement would be contrary to the principles on which we are working, and accordingly the required grades of resistance should be based on the contemplated use of the buildings at the time of erection.

134. None arises, of course, when the occupancy change involves a reduction in the hazard. When the hazard is increased, *e.g.* the change is to an occupancy of greater fire load or from a normal to an abnormal occupancy, questions only arise if the capacity of the building exceeds the maximum proposed for the higher risk. In such cases the installation of a sprinkler system or subdivision of the floor area by means of lightweight fire resisting partitions would raise the standard of the precautions to the level required for the higher risk. These difficulties have often been raised as almost insuperable obstacles preventing the proper design of fire precautions in relation to the hazard, but as it is illogical to design the floors of a block of flats for a warehouse or factory loading, it appears equally illogical to design fire precautions for hazards greater than those expected from the primary use of the building, unless some change of occupancy is anticipated.

135. The question is one which the Committee considered at length. It is obviously one which must be of concern to authorities who are charged with the making of rules or regulations to minimize fires and the spread of fires. It is for such authorities to consider what policy they will adopt with regard to fire resistance in new buildings of a nature which experience suggests may ultimately house higher fire risks than those contemplated at the time of building.

USE OF COMBUSTIBLE MATERIALS IN BUILDINGS OF GRADED TYPES

TYPES 1–3 CONSTRUCTION

136. It has been recommended (paragraph 59) that the use of combustible material should be excluded from structural parts of buildings of Types 1–3. Except as proposed below, combustible material may otherwise be used for decorative linings, floor surfacings, window frames, and similar non-structural parts provided that proper precautions are taken where necessary. Thus a common finish to concrete floors consists of timber boarding on battens. The void beneath

the boarding provides a possible means of spread of fire, and accordingly suitable fire stopping of incombustible material should be provided transversely to the battens at distances apart not exceeding 25 ft., under all partitions, or over the whole area.

Buildings more than 100 *ft. high*

137. Because of the increased difficulties and risks associated with fires in high buildings, it is desirable to limit as far as possible the use of combustible material not only in structural elements but in other parts also. Although the amount of combustible material in such items as doors, wall linings, etc., may not be appreciable from the standpoint of fire load, they present possible sources of ignition and add to the fire. The use of metal furniture and equipment, framing, trim, incombustible floor and wall surfaces, would be preferred, but we appreciate that the use of certain combustible materials may be very desirable from other standpoints, *e.g.* thermal insulation. There would be no objection to the use of such combustible materials for these particular purposes, provided they are applied in a manner which is unlikely to add appreciably to the risk of fire, *e.g.* combustible insulating material, suitably treated on the exposed surface, used as permanent shuttering for poured concrete.

TYPE 4 CONSTRUCTION

138. In view of the fact that Type 4 construction is not expected to resist a complete burn-out, we propose that the suggested limitation on the use of combustible materials for the internal floor structure should be relaxed, and accordingly a timber floor of ½ hour fire resistance might be used. A timber roof with suitable ceiling protection could also be used.

TYPE 6 CONSTRUCTION

139. The use of combustible materials in Type 6 construction should be limited to wall and roof linings, doors, skirtings, and the like.

USE OF FLAME RETARDANT TIMBER

140. The treatment of timber with various solutions with the object of rendering it incombustible has been the subject of much study, and methods have been developed on a commercial scale for impregnating timber with suitable materials. Such timber is often described as "fire-proofed timber," but there is no evidence to suggest that that term can be interpreted literally, and it is preferable to adopt a term such as "flame retardant" timber. There is no doubt that proper treatments of this kind markedly reduce the ease of ignition of timber and prevent it flaming, and the material shows marked differences from untreated timber in those respects. This should tend to reduce the incidence of fire. When exposed to fire, however, the treated timber chars, and if the fire is of sufficient intensity and duration, the timber is destroyed.

Fire resistance tests have been carried out in America on framed walls and partitions in which timber treated with ammonium phosphate was used, and certain preliminary tests have been made by the Building Research Station. These tests show that from the fire resistance standpoint, *i.e.* as defined in *B.S.* 476–1932, the substitution of timber treated in this way afforded no advantages over untreated timber, but the behaviour of mixtures of impregnating salts has not been studied in this respect. The use of treated timber may, however, prevent a fire developing or at least reduce its severity in buildings where the woodwork contributes the main source of fuel. It must be noted, however, that impregnation may not penetrate more than a short distance from the surface of a member, and the timber in the core will burn if conditions are sufficiently severe to cause the impregnated layer to char and fall away. The use of built-up members, the laminae of which are impregnated before fabrication, would, however, largely remove this difficulty, and it is understood that the industry is giving attention to such developments.

141. Reference to the use of flame retardant timber is found in several building regulations. Thus, in London, softwoods impregnated throughout with ammonium phosphate are accepted as an alternative to hardwoods for the construction of enclosed and protected staircases. In the Canadian Building Code, timber treated with fire retardant chemicals in accordance with the requirements of A.S.T.M. Specification C. 132–40 T. is accepted for use broadly under the same conditions as unprotected steel. Whilst, therefore, there is evidence that timber properly impregnated has been recognized as affording advantages over untreated timber, we have concluded that until standards for impregnated timber have been established in this country it would not be practicable to make definite recommendations for its use.

OPENINGS IN FIRE RESISTING INTERNAL WALLS AND FLOORS

PROTECTION OF OPENINGS IN FIRE RESISTING INTERNAL WALLS

142. Openings formed in a fire resisting wall should be protected so as to afford a similar degree of fire resistance to that required for the wall. An opening protected to this standard we propose to call a "protected opening." Generally, in the past, iron and steel doors and shutters have been used for this purpose and, especially where double doors have been fitted, have given satisfactory service. It must be noted, however, that the unexposed side of this type of protection may become very hot during a fire, and, although passage of flame is prevented, the full grade of fire resistance required for the wall would not be attained. Accordingly, in the conditions laid down in *B.S.* 476 for testing iron and steel doors and shutters, the criterion of failure of temperature rise on the unexposed face is waived. Some justification for the above relaxation lies in the fact that, whereas combustible contents are often placed in contact with wall surfaces, the space on either side of an opening should always be clear to permit unobstructed passageway. It may be noted here that the threshold, *i.e.* the floor immediately adjacent to and within the opening, should be wholly of incombustible material.

Obviously even protected openings provide a source of weakness in a fire resisting wall, and it is thus reasonable to restrict the amount of openings which might be made. We deem it desirable that openings in any wall forming a fire resisting separation should be limited in number and size, and the competent authority should exercise discretion in this respect. As a basis, we suggest that the aggregate width of all openings in any wall of a storey should not exceed one-half the length of the wall. Further details of protection by fire resisting doors, etc., will be dealt with in Part II, and we propose also to consider the question of sizes of individual openings in that part of the Report.

PROTECTION OF SHAFTS

143. For this Report we define a shaft as a space extending through one or more floors and serving two or more storeys of a building. The shaft may contain a staircase, passenger lift, goods hoist or ramp, but we exclude under this definition ducts forming part of a ventilating system, for services, pipes, etc., which nevertheless require consideration in this connection.[1]

The need for protection of vertical shafts hardly calls for emphasis here. They form a ready means of passage of fire from storey to storey, the danger being

[1] See, for example, British Standard Code of Practice, *B.S.* 1043–1942, *The Provision of Engineering and Utility Services in Buildings*, Part V.

accentuated by the flue effect created by a fire. This effect is less apparent in staircases where the landings, flights of stairs, and particularly the newel walls where they exist, afford some baffle to the spread of fire; but staircases constitute a means of access for fire fighting, and the shaft enclosures should therefore be of a high standard of fire resistance.

144. The baffle which exists in a staircase is absent from a lift or similar shaft, and, moreover, in such a shaft a fire in the lower storeys spreading into the shaft results in a direct attack on all compartments above. In these circumstances it is considered that the enclosures to lift and similar shafts should have a fire resistance not less than that of staircase enclosures. However, where a shaft does not exceed 100 sq. ft. in area it is considered that as the fire would have to penetrate the enclosing walls on two floors before spread could occur, it is reasonable to assume that sufficient protection would be afforded if the overall resistance on both floors were sufficient, *e.g.* if the floor were of 4 hours fire resistance, the shaft walls would afford sufficient protection if they were of 2 hours fire resistance. We give in Table 9 proposed fire resistance requirements for walls of shafts. No provision is made in buildings of Types 5 and 7 construction, since in those instances the problem is one which must be considered essentially from the standpoint of means of escape, for, as no fire resistance is required in the floor, it would be onerous to specify that the shaft should be enclosed by fire-resisting construction. Even so, there is good reason for enclosing the shafts because although the ordinary timber floor cannot be included in even the lowest grade laid down in the *B.S.* 476, *i.e.* ½ hour, it does possess a short period of resistance which may be valuable in limiting the rate of spread from floor to floor.

TABLE 9

TYPE OF CONSTRUCTION	FIRE RESISTANCE OF SHAFT WALLS (IN HOURS)	
	Staircase Shafts; Access Shafts for Fire Fighting; Other Shafts exceeding 100 sq. ft. in Area	Other Shafts
1	4	2
2	2	1
3	1	1
4	½	½

Enclosure of Top and Bottom Ends of Shafts

145. Certain special factors must be taken into account in closing the ends of shafts.

Top End. When the shaft does not continue to the top storey of a building it should be covered by a construction having the same grade of fire resistance as that of the floor in which the shaft terminates. No difficulty arises when the enclosing walls are continued throughout the height of the storey where the shaft terminates, and abut the soffit of the next floor above.

When the walls terminate at the soffit of the floor in which the shaft terminates, and access to the shaft is required, a trap door or hatch is necessary. This should be tight fitting and of the same grade of fire resistance as the floor.

When the shaft continues to the top storey, it should be carried through any roof space and the roof, and provision made for ventilating the shaft either by continuing it for a height of at least 3 ft. above the highest point at which the roof abuts on the shaft, and providing smoke vents having an area equal to at least one-third of the area of the shaft at the top, or by some equivalent means. We regard this feature as desirable from the standpoint of venting the shaft under certain conditions, for if the shaft walls on one storey failed under fire, the "venting" would not only draw off smoke and fumes but minimize the attack of the fire on the walls above.

146. *Bottom End.* When the shaft does not extend to the lowest floor of a building, the bottom end should be closed by a floor or trap door as proposed for the top end.

Openings in Shaft Enclosing Walls

147. All openings in walls enclosing shafts should be protected openings.

148. Borrowed lights present a difficult problem in staircase shafts, escalator, halls or shafts from the fire protection standpoint, especially in buildings of the higher grades of fire resistance. Available data indicate that a panel of glass bricks when properly fixed affords 1 hour fire resistance, and fire-resisting glazing ½ hour. It seems desirable, therefore, not to include such lights in staircase shafts, the walls of which are required to be of a higher resistance than that obtainable from either of these methods of construction.

EXCEPTIONS TO PROPOSED RECOMMENDATION FOR SHAFTS

149. From the standpoint of fire spread the proposals for the enclosure of shafts need not, of course, apply to lift shafts built within a staircase shaft if the former are stopped at the bottom in the manner described above. If the floor cannot be made imperforate, as, for example, when operating cables, etc., are required to pass through it to operating gear at the bottom, the enclosure should be of the appropriate standard. The proposals need not apply to shafts external to the building except in respect of protection of openings in the enclosing wall giving access directly to and from the building.

SMOKE EXTRACTS FROM BASEMENTS (INCLUDING SUB-BASEMENTS)

150. When fire occurs in storeys below ground where no provision has been made for natural ventilation by window or other openings, the accumulation of smoke and hot gases renders fire fighting very difficult, even in its early stages, [illegible]

WE THEREFORE SUGGEST:

i. Unobstructed smoke extracts having direct communication with the open air should be provided in or adjoining the external walls and in positions easily accessible for firemen in an emergency.

ii. The area of smoke extracts to be provided should take account of the nature of the occupancy. They should be distributed as far as possible around the perimeter to encourage flow of smoke and gases. Where it is impracticable to provide a few large extracts, *e.g.* not less than 30 sq. ft. in area, a number of smaller extracts having the same gross area should be installed.

iii. Covers to the smoke extracts should, where practicable, be provided in the stallboard and/or pavement lights at pavement level, and be constructed of light cast iron frame or other construction which may be readily broken by firemen in an emergency. The covers should be suitably marked.

iv. Where they pass through fire-resisting separations smoke extracts should in all cases be completely separated from other compartments in the building by enclosures of the appropriate grade of fire resistance. In other cases sheet metal ducts may be provided.

v. Where there are sub-basements the position of the smoke extracts from sub-basements and basements should be suitably indicated and distinguished on the external faces of the building.

FIRE TOWERS

151. Although fire towers should strictly be considered in this Part of the Report as they are designed essentially for access by firemen, it is more convenient to treat them at the same time as staircases for means of escape, and accordingly the matter will be dealt with in Part III.

EXPOSURE HAZARD

152. So far we have confined our attention to precautions against internal hazards in a building. We have now to consider the question of obtaining protection against spread of fire between buildings, *i.e.* against exposure hazard.

153. For the purpose of this Report, exposure hazard is defined as the risk of fire spreading into a building through the open air from a fire in other buildings, stacks of combustible material, etc.; or into a division or compartment of a building through the open air from a fire in other divisions or compartments of the same building. It does not include the risk of fire entering a building, division, or compartment directly through separating or division walls or floors or through vertical shafts, *e.g.* staircases.

154. When a building is being considered from the standpoint of the risk of entry of fire it will be called the "*exposed*" building, and it is emphasized that only the measures necessary to afford protection of openings in walls against entry of fire have been considered. When a building is on fire, and creating a risk to the "exposed" buildings, it is called the "*exposing*" building.

155. In the recommendations as to the protection of window and other openings in external walls to limit the exposure hazard, distance from another building, etc., has usually been adopted as the criterion. It is obvious that this does not refer solely to "distance from another *existing* building," for if it did, the case would arise where a building built opposite to or adjoining an open site would have no protection against the risk which would arise to it when a building opposite or adjoining was erected. Accordingly, if and when our recommendations are implemented, it will be necessary to take steps to ensure that buildings are protected

against future as well as existing risks, either at the time of erection, or when the opposing or adjoining buildings are erected.

156. Spread of fire between buildings due to exposure is the major cause of conflagrations. Up to the outbreak of war, our relative freedom from conflagrations on the vast scale experienced in other countries can be attributed to two main factors; firstly, the infrequent use of combustible materials for the construction of external walls and the external covering of the roofs, and secondly, the fact that trade and industrial buildings presenting a high fire risk are often surrounded by small houses which present a much smaller risk and do not therefore provide a ready means of spread. In some areas, however, *e.g.* the commercial centres of towns, a high conflagration risk exists because of the aggregation of trade buildings without adequate fire breaks, and to keep the risk within bounds heavy expenditure on fire fighting forces has been necessary. Even with strong fire fighting forces there have been some serious conflagrations in peace-time, and it is considered that there is room for improvement on pre-war standards of security.

157. The conditions set up by incendiary attack differ widely from those resulting from one or two simultaneous outbreaks of fire in peace-time, and much greater reliance has to be placed on structural measures in the former case. Investigations carried out in war-time have, however, given valuable information on the general problem. In those cases where conditions have approximated more closely to those experienced during peace-time fires, the results have generally tended to confirm that pre-war standards against exposure hazard were not always adequate, although mention should be made of the good performance of many modern buildings in which provision was made against the normal peace-time hazard.

EXISTING REGULATIONS FOR PROTECTION AGAINST EXPOSURE

BRITISH REGULATIONS

158. Existing regulations include certain local bye-laws conforming with the Model Series of Bye-laws of the Ministry of Health. These local bye-laws deal only with buildings which are considered to present special exposure hazards, *e.g.* the building with combustible external walls; they are summarized in Appendix 5. In addition, some authorities, *e.g.* Liverpool Corporation, have requirements in respect of warehouses, whilst the London County Council deal with the matter in respect of buildings or divisions of buildings of the trade or warehouse class in which the cubical extent exceeds the limit of 250,000 cu. ft. laid down in the London Building Act. We understand that the provision of protection against exposure may be included in the conditions of consent for the erection of such buildings; window openings, etc., which are within certain distances of openings in other buildings are required to be protected. Mention may also be made of the Rules of the Fire Offices' Committee for Wired Glass and Electro Copper Glazing and for External Drencher Installations.

AMERICAN AND CANADIAN REGULATIONS

159. The various American building codes and the Canadian Building Code include comprehensive regulations dealing with protection against exposure. Protection of window openings which are within certain distances of other buildings is required, and in some codes the distance varies according to the occupancy of the building. In addition, in the Californian and Canadian Codes, the percentage amount of window openings in external walls is limited; at distances less than 10 ft. between buildings no openings are permitted, the percentage subsequently increasing roughly in proportion to the distance. The situation of the opening, *i.e.* whether it overlooks a street, etc., is also a factor taken into account. Reliance is

placed mainly on the protection afforded by wired glass, which is variously assumed to offer 1 hour, ¾ hour, or ½ hour resistance in different codes. A significant feature of these codes is the adoption of a system of fire zoning, whereby cities and towns are arbitrarily divided into two or three zones in which restrictions are imposed on the construction that may be erected in a zone and the occupancy of the building, but we are informed on good authority that increasing difficulties are being encountered in its application.

ASSESSMENT OF EXPOSURE HAZARD

160. An adequate assessment of the severity of the exposure hazard should be the first step towards the formulation of any general recommendation for the necessary protection. At the present time, however, data are very meagre and it is only possible to consider the problem on a qualitative basis.

161. Fire may be carried from one building to another by one or, more usually, a combination of the following agencies: (1) Direct contact of flames and hot gases emitted from the burning building with combustible material on and in the exposed building, *i.e.* convected heat; (2) radiated heat; (3) flying brands.

162. Whilst the intensity of radiation falling on an exposed building is independent of wind, flame effects are largely dependent on wind conditions and on a variety of other factors, but in general it would appear that they have a smaller range of action than radiation. Hot gases may also be sufficient to ignite combustible material at much greater distances than flames, whilst there have been instances of fire being carried by flying brands to buildings half a mile or more from the outbreak; these latter incidents must be regarded as uncommon risks against which provision need not be made.

163. The severity of the exposure could be determined by recording the temperatures attained at various distances from a fire and thence, by comparison with a standard time-temperature curve, it would be possible to assess the severity in terms of this standard heating. Then the grade of protection required at various distances from the fire could be determined. The changes (see Appendix IV) which occur in brickwork mortar and concrete when exposed to high temperatures could also be used for that purpose but no data are available.

164. Clearly the hazard will be determined by a number of factors relating to both the "exposed" and "exposing" building; a great variety of exposure conditions will therefore prevail, and until it is possible to establish a rational basis for assessing the severity of the exposure it is necessary largely to rely on experience. Nevertheless, although a quantitative approach is not yet possible, a brief general survey of the factors which influence the severity of the hazard will not be out of place.

FACTORS INFLUENCING SEVERITY OF HAZARD

165. The main factors to be taken into account are:

Type of construction of buildings.
Amount of window openings, etc., on opposing elevations.
Distance between the buildings.
Size of buildings.
Occupancy of buildings.
Automatic sprinkler protection.

TYPE OF CONSTRUCTION OF BUILDINGS

166. As regards the exposing building, the whole of the construction is important because if the internal construction is fire resisting, the outbreak is less likely to

spread throughout the building, and the size of fire is restricted. Again, the building with combustible external walls will clearly create a greater hazard than the brick walled building. As regards the exposed building, the nature and fire resistance of the external walls and roof are the chief factors. Here again combustible walls obviously increase the risk of spread as compared with an incombustible wall. The imperforate brick wall of high fire resistance virtually eliminates the risk of ignition of material stored in contact with its inner face; on the other hand, the sheet metal wall, *e.g.* corrugated steel, would present a much greater risk in that respect.

AMOUNT OF WINDOW OPENINGS

167. In buildings having external walls of incombustible fire resisting construction, the openings constitute the vulnerable feature, and large amounts of window opening obviously facilitate spread of fire.

DISTANCE BETWEEN BUILDINGS

168. The effect of increasing distance between the buildings is to reduce the severity of the exposure, *e.g.* the radiation intensity diminishes inversely as the square of the distance.

SIZE OF BUILDINGS

169. If buildings are of the same type of construction then clearly the larger building will tend to create a higher risk to an exposed building if the former is on fire, and its protection against entry of fire will present greater difficulties than a small one. Height is specially important in certain cases (paragraph 211).

OCCUPANCY

170. Occupancy influences the severity of the fire; the fire in the storage building of high fire load will usually be hotter and may last longer than a fire in an office building of the same size, and the risk of spread to other buildings will be greater. The occupancy of the exposed building has an indirect bearing on the problem. The risk of entry of fire into the building may be the same for a high as for a low fire load occupancy, but the greater risk arising from an outbreak of fire in the former warrants more stringent precautions against entry.

AUTOMATIC SPRINKLER PROTECTION AND ALARM SYSTEMS

171. The installation of a sprinkler system reduces greatly the chances of an outbreak developing into a large fire, whilst a fire alarm system ensures early warning of an outbreak. These are factors which do not affect the potential hazard once the fire develops, but, by minimizing the chance of the fire developing, reduce the overall hazard. For example, if every building were equipped with a sprinkler installation, serious fires might be so reduced in number that protection of window openings would be unnecessary.

METHODS OF PROTECTION AGAINST EXPOSURE

172. Having reviewed generally the various factors which influence the severity of the hazard, we now consider the means available for obtaining the desired degree of security. The measures which can be adopted, either singly or in suitable combination, are:

Space separation of buildings.
Requirements in respect of walls and roof coverings.
Protection of openings, including drenchers.
Sprinkler protection.
Fire fighting by fire services.

173. It is necessary, however, to consider first how the effect of the factors discussed in paragraphs 166–170 can be taken into account. General recommendations which took account of each factor would clearly be very complicated, as they would vary according to the size, occupancy, type of construction, etc. To formulate our recommendations we have been obliged to reduce the number of variable factors by making certain assumptions which are justified by the fact that the constructional measures, *e.g.* protection of window openings, are but one of the available means of protection. Where, in principle, this may lead to deficiencies, greater reliance must be placed on fire fighting.

174. The assumptions are as follows:

a. No distinction is necessary between buildings having different percentages of window openings except when the amount exceeds 50 per cent of the area of the elevation, exclusive of show windows on the ground floor.

b. Differences in hazard due to different occupancies can be neglected except in respect of occupancies of low fire load.

c. Variations in the size of buildings need not be taken into account in detail, but it is proposed that certain relaxations should apply to buildings which are less than a specified size.

d. No distinction is necessary between the requirements for buildings of Types 1–5 construction.

SPACE SEPARATION OF BUILDINGS

175. Except when separated by imperforate walls having adequate fire resistance, the separation of buildings by a space across which fire cannot spread is the fundamental method of protection, and for certain classes of buildings, *e.g.* those with easily combustible external walls or roof coverings, spacing may be the only means of ensuring reasonable safety. Consideration of the problem in relation to spacing involves questions which fall within the scope of town planning, the width of streets and height of buildings in relation thereto, amount of site cover, etc., and it would be possible to develop a system whereby sufficient protection could be assured by the utilization of these factors alone.

176. In built-up areas much can be done by improved development of individual sites which may come under town planning considerations. In the past the tendency has been to develop building sites by the erection of buildings belonging to different owners on the perimeter of the site, usually bounded by streets, in order to obtain maximum street frontage. This has resulted in the formation at the rear of the buildings of light wells, courts, yards, etc., presenting a high exposure hazard which is often accentuated by their inaccessibility for fire fighting. Conditions may be aggravated by the erection of accessory buildings, so that ultimately the whole site becomes covered with buildings without adequate fire breaks.

177. When a site is developed with one large building, considerable advantages may accrue in respect of light and air by the adoption of an open plan type. This type of plan may sometimes require a greater height of building to afford the same floor area as the closed court type, but from the fire fighting standpoint the advantages that are gained by the elimination of the light well and the readily accessible elevation easily outweigh the effects of the slightly increased height. In general a small increase in the height of buildings would enable the amount of site cover to be reduced considerably, with, consequently, a greater separation of buildings and better light and air. These aspects of town planning in relation to fire safety are dealt with at greater length in a paper in the Institute of Civil Defence *Journal* 1943, Vol. 5, No. 3.

178. The "use zoning" of land, whereby factories may be located in one zone,

commercial buildings in another, etc., may create areas of high conflagration risk if proper safeguards are not introduced. As already mentioned, the intermingling of industrial and commercial buildings with dwelling houses has tended in the past to minimize the risk of conflagration, and segregation of the types of property will undoubtedly accentuate the risk in the case of the industrial or commercial zone, unless adequate precautions are taken.

179. Before leaving this aspect of the problem, further reference should be made to the fire zoning of cities and towns which is a characteristic of American codes. By means of "fire zoning," restrictions are imposed on the type of construction and nature of occupancy which can be included in any zone, the object being to ensure that all buildings erected in those zones where the volume density of building is high, *e.g.* central area of a town, shall be fire resisting. Types of construction which present serious exposure risks may be erected only in zones where the density is generally lower. This implies a greater spacing between buildings of the latter class.

180. We have carefully considered the desirability of entering into these fields and had in fact considered a tentative scheme of fire zoning; there is no doubt much to be said in its favour, and the question might be considered by local authorities under their town planning powers. However, as we were faced with the difficult problems associated with rebuilding in the existing congested areas of towns and cities as well as the problems associated with building on virgin sites, where space is not so restricted, we concluded that, as other methods of attaining reasonable protection were available, we should endeavour to find a solution applicable to both the built-up area and the undeveloped area. Our solution is based, in the case of buildings with walls and roofs of an adequate grade of fire resistance, on the fact that no matter how close together the buildings are located, it is not impossible to reduce to reasonable proportions the risk of spread of fire from one building to another by suitable protection of openings in the walls and roofs; in the case of buildings with lower grades of external fire resistance, however, we have had to recommend minimum distances which must be maintained between buildings in order to reduce risk of fire spread. It must not be assumed that by adopting this line of argument we do not regard greater dispersal of buildings as desirable. Any proposals which control the density of building, such as those indicated in the Model Clauses issued by the Ministry of Health for use in the preparation of schemes for town and country planning, will undoubtedly contribute to fire safety.

181. It is to be realized that in built-up areas the precautions we recommend will not become fully effective until the whole of the buildings in the area have been rebuilt. If we had applied generally a standard of protection that would ensure full safety from the high exposure risks existing in built-up areas, it would have been so onerous as to restrict development in undeveloped areas where each building can be required to bear a proper share of the precautions necessary for providing the adequate fire separation from its neighbour.

REQUIREMENTS IN RESPECT OF EXTERNAL WALLS AND ROOF COVERINGS

Incombustible External Walls (Types 1–5 Construction)

182. The external walls of a building should withstand the effects of internal fire and reduce the risk of fire entering the building; accordingly the wall must have adequate fire resistance in both respects. A fire resistance of 4 hours has been adopted as sufficient for separating walls, and on that basis it is reasonable to assume (though the assumption is not strictly accurate) that two external walls each of 2 hours fire resistance will afford the same protection if erected in contact with each other. If, however, the walls are separated by a sufficient distance and have no openings in them, a fire resistance of less than 2 hours would be adequate

for the wall of the exposed building, because of the reduced hazard. On the other hand, the resistance recommended against internal fire, based on fire load, is 4 hours in the case of fully protected buildings of high fire load, and 2 hours generally for other buildings. These standards would therefore satisfy conditions in respect of external exposure. We have, however, suggested that in the case of fully framed buildings of low fire load not exceeding 50 ft. in height, external walls of 1 hour fire resistance against internal fire may be adopted, and, in these cases, we recommend that the walls should be located at a distance of 10 ft. (measured at right angles to the wall) from the walls of other buildings.

It should be observed that these recommendations have regard to the fact that the usual types of external wall (*e.g.* solid brickwork or concrete) afford the same grade of fire resistance whichever side is exposed to fire. It appears probable that composite types of wall construction which will offer different resistance against fire on the internal and external surfaces may be more freely adopted in the future. Such walls may therefore afford the recommended grade against internal fire, but offer a reduced grade against external exposure. In these cases separate consideration, according to spacing, occupancy and other relevant factors, will be necessary from the standpoint of exposure alone.

Incombustible External Walls (Type 6 *Construction)*

183. Insistence on the above standards would rule out many types of external wall which are commonly in use at the present time, and for which provision is made in the general scheme of grading by the inclusion of Type 6 construction. As indicated in paragraph 182, walls having a lesser fire resistance than 2 hours will need separation. The distances from other walls at which these incombustible walls may be erected should be related to the distances at which window protection of the same grade of fire resistance is required. We therefore suggest that, except as provided for in paragraph 182, the distances between walls of 1 hour fire resistance and between walls of ½ hour fire resistance against external fire should be the minimum distance at which the corresponding grade of window protection is required. If the wall is of less than ½ hour fire resistance it should be built at a distance from walls of other buildings at which window protection is not required. These distances are set out in our recommendations with regard to the protection of window openings. It is, however, necessary to take account also of the risk of collapse of buildings of this type due to internal fire, and the separation must be adequate in respect of both this and the exposure hazard. We therefore propose that, notwithstanding the above requirement, there should be a minimum separation equal to at least three-quarters of the height of the building.

184. Relaxation from these proposals might be permitted in respect of buildings of this type which do not exceed 20,000 cu. ft. in cubic capacity or 15 ft. in height, or if the building is separated from another building by an imperforate wall of at least 4 hours fire resistance.

Combustible External Walls (Type 7 *Construction)*

185. The Model Bye-laws of the Ministry of Health, on which are based most of the bye-laws of local authorities in England and Wales, regulate the use of combustible materials for external walls in a number of clauses summarized in Appendix V. Because timber has seldom been used on a large scale in this country, except for hutted camps in war-time, few data are available to assess the adequacy of these requirements. They might be sufficient for occasional buildings erected in an area where normal brick walls were the rule, but it is doubtful whether they would be satisfactory in an area covered with buildings with combustible walls. It is, of course, well known that fire may spread across far greater distances than are specified, and whilst we cannot justify any general increase, we regard the existing separation as the minimum consistent with safety, provided there

is no increase in the use of combustible materials for external walls. We feel, however, that each proposal for using combustible external walls on an extensive scale in any one area should be considered separately, bearing in mind, however, the fact that combustible materials may differ widely in their fire susceptibility, *e.g.* heavy timber is less susceptible than plywood.

Roofs with Fire-Retardant Coverings [1]

186. From the standpoint of minimizing the risk of entry of fire into a building, the roof has to perform the same function as the wall. The reinforced concrete roof can be regarded as comparable with a brick wall, but the normal pitched roof, consisting of timber framing covered with slates, tiles, metal sheeting, etc., has by comparison a relatively low degree of resistance, the roof covering alone affording the necessary protection. Reasonable security from conflagration has been attained by insistence generally on the use of such roof coverings because they do not ignite or spread flame easily, cannot produce flying brands, and afford a reasonable amount of protection to the combustible supporting structure. Most of these materials are incombustible, and although asphalt and some other roof coverings containing bitumen are combustible, they are nevertheless accepted when used on a suitable base. Asphalt as laid on roofs may in fact be regarded as virtually incombustible.

187. We understand that before the war a test was being developed at the Building Research Station whereby the resistance of various forms of roof construction to standard conditions of exposure could be assessed. The test took account not only of the nature of the covering, but also the effect of any roof lining and the general construction of the roof. A preliminary grading of roof systems in respect of their resistance to exposure hazard was thus developed, but we consider further work is required to correlate the results more closely with behaviour in practice before the test could be adopted as a basis for requirements.

188. Because all suitable roof coverings are not incombustible as defined in the *B.S.* 476–1932, we propose to apply the term *fire-retardant* to a roof covering which affords reasonable security against exposure. The roof coverings which we regard as falling into this category are mainly those specified in Clause 78 of the Model Bye-laws of the Ministry of Health, and are as follows:

1. Clay, concrete, asbestos cement, stone or glass tiles.
2. Natural or asbestos cement slates.
3. Asphalt mastic.
4. Lead, copper, zinc, aluminium.
5. Asbestos cement sheeting, wired glass, steel sheeting galvanized or protected with bituminous material with or without mineral fibre.
6. Bituminous roofing felt, made with animal or vegetable fibre, covered with incombustible material such as cement mortar not less than ½ in. thick, sand, ballast, granite or other stone chippings, or with bituminous macadam.
7. Bituminous roofing felt, made with animal or vegetable fibre, on an incombustible base.
8. Bituminous roofing felt made with mineral fibre.

We have not entered into the question of detailed specifications for the materials containing bitumen, but would draw attention to the fact that the composition is a matter which must be considered from the fire protection standpoint.

[1] The term "covering" applies only to the external waterproofing membrane, *e.g.* tiles, slates, asphalt mastic, etc. It does not include any underlay or lining such as felt or boarding.

Roofs with Non-Fire Retardant Coverings

189. Roof coverings which do not fall within the fire retardant category present very high risks because they are easily ignited by flying brands, and some at least are potential sources of brands. The question is dealt with at some length because high risks can be created by the extensive use of such materials.

190. The Model Bye-laws regulate the use of roof coverings of this kind by providing that a roof may be so covered if the building is erected at a distance of at least twice its height from the nearest boundary, and from any other building. We understand that this or a similar Bye-law has been widely in force for a number of years. It was framed primarily in terms of thatch, and the concession is permitted only for domestic buildings as defined in the Bye-laws. Whilst it may have given adequate security when applied to thatch, which is infrequently used, we do not consider the basis on which it is founded to be satisfactory for other materials, nor is it entirely logical, for it leads to the anomalous position of permitting a domestic building of considerable area to be spaced at the same distance from the boundary as a small cottage of the same height. The possibility of modifying the principle has been considered but, in the absence of data, we have been forced to retain it. We have, however, thought it desirable to limit the size of buildings so covered, and have considered separately the applicability of the Bye-law to each of the following materials:

Thatch.

Bituminous roofing felts not used in accordance with 6, 7 or 8 above, including bituminous (or asphalt) shingles.

Wood shingles.

Plywood.

191. *Thatch.* Accurate statistics on the adequacy of the provision in terms of thatch are not available, but there is clear evidence of the risks of thatch, in that the ignition of one thatched roof in a row of thatched cottages almost inevitably means that contiguous houses are set alight. To overcome the anomaly which is found in the Bye-law, we suggest that the cubic capacity of any thatched building should not exceed 36,000 cu. ft.—the figure quoted in the Bye-laws as the maximum cubic capacity of a building having certain types of external walls (see Appendix V). Within this limit the building may consist of a pair of semi-detached cottages.

192. *Bituminous Felts and Shingles with Animal or Vegetable Fibre.* The Model Bye-laws accept as a suitable roof covering, bituminous material on a base of boards, provided it is covered with a defined thickness of incombustible material, or is laid on a base of concrete, etc. The unprotected material on boards falls within the classification of non-fire retardant coverings. Although this material may not be so vulnerable as thatch and is not so serious a source of flying brands as, for example, wood shingles, the combustibility of roofs of this kind precludes any general relaxation of the Bye-law. We suggest that the qualification which we propose for thatch should be made applicable to this material also, when used without an incombustible covering on boards or on other combustible bases. Bituminous (or asphalt) shingles, consisting of surface-treated felts made up to resemble clay tiles, would be comparable with ordinary bituminous felts and may in fact present a somewhat higher risk because of the greater ease of ignition of the loose edges. We regard the Bye-law separation as the minimum consistent with safety, and the limit of size above should apply.

193. *Wood Shingles.* The woods commonly used are oak and cedar. Oak shingles have been traditionally used on church steeples, and do not appear to call for special comment when their use is restricted to this purpose where the steep pitch prevents lodgment of brands. The data which we have available on the fire risks of cedar shingles in America, where they have been extensively used, form a record of disastrous conflagrations involving whole townships. The evidence

indicates that one of the chief hazards is the multitude of flying brands which this form of roofing produces. These brands are able to ignite similar roofs at distances of ¼ mile or more. In one instance, for example, of a fire in a shingle roofed house, it is significant that the brands ignited only those houses in the neighbourhood which were similarly covered. So far as is known there is no means of making the shingles permanently less inflammable, and in the light of present knowledge we would propose that in general the use of this form of roofing should be prohibited. We have, in arriving at this decision, not neglected the fact that the effects in America may have been intensified by the greater wind velocities which are often experienced, and by the lower humidities which persist in certain areas, although after periods of summer drought in this country shingle roofs would be very dry.

194. *Plywood.* Recent developments in the use of synthetic resin adhesives has enabled plywood to be used externally without risk of separation of the plies by weathering. The plywood may be simply bonded, or bonded and impregnated with the resin. Whilst it seems that the use of resin for bonding the plywood alone would not influence its ignitibility, it is claimed that the impregnated plywood has quite different properties. We have insufficient data on this impregnated material to justify relaxation of the spacing, and in respect of the non-impregnated plywood we consider the Model Bye-law requirement a minimum.

TREATMENT OF OPENINGS IN EXTERNAL WALLS

Limitation of Amount of Openings

195. We have considered the possibility of direct limitation of the amount of openings in an external wall in relation to the distance of the wall from openings in other buildings, in a manner similar to that adopted in some of the American building codes as a means of obtaining protection against exposure. We are considering not only building in undeveloped areas but also rebuilding in congested areas where the need for light and air, and consequently for window openings, is greatest where the streets are narrowest. It seemed undesirable to impose any direct restriction on the amount of window opening, except as regards the maximum which could reasonably be permitted before the amount of wall remaining became so small as to offer virtually no protection. For this maximum we have adopted an area of 50 per cent of the area of elevation above the ground storey measured between the floor over the ground storey and ceiling of the topmost storey. There are in addition other factors which automatically limit the area of openings (see paragraph 212).

Methods of Protecting Window Openings

196. The methods of protecting window openings which have been considered are:

- a. Fire resisting glazing in metal frames, *e.g.* wired glass, electro-copper glazing.
- b. Glass bricks.
- c. Automatic external drenchers alone or in conjunction with (a) or (b) above.
- d. Fire resisting shutters either internal or external.

197. *Fire Resisting Glazing.* This has been widely adopted in the past as a means of protecting window openings. Experience shows that, if properly fixed, it can be relied on to give reasonable protection within certain limits of distance and time. No test of fire resistance strictly in accordance with *B.S.* 476 has been carried out, but recent tests made by the Underwriters' Laboratory in America, confirming previous tests carried out by the British Fire Prevention Committee in this country, suggest that where the glazing conforms with the rules of the

Fire Offices' Committee for wired glass, etc., or of the corresponding rules of the London County Council, it can be assumed to afford Grade E fire resistance.

198. *Glass Bricks.* These are a relatively recent innovation in this country and their behaviour under fire seems to be dependent on the provision of an adequate expansion joint. In one instance of an actual fire, panels successfully withstood the whole period of fire, and a fire resistance test carried out on a panel about 6 ft. by 6 ft. with an adequate expansion joint, in accordance with the British Standard test for glazing, showed that it would comply with the test conditions for 1 hour.

199. *Automatic Drenchers.* The successful use of external drenchers depends, of course, on the availability of adequate water. There is the risk that during a fire, when heavy demands are being made on water, the pressure at the heads will be insufficient to give the flow necessary for adequate protection. Drenchers afford valuable protection to plain glass, whilst a much higher standard is attained if they are used in conjunction with fire resisting glazing.

200. *Fire Resisting Shutters.* External steel shutters, hand operated or automatic, are, in theory, clearly an effective means of defence, but considerable difficulties can be expected in practice. They need careful maintenance to ensure ease of operation after exposure to weather. Shutters fixed inside window openings do not appear to have been developed as much as they seem to deserve: a good automatic shutter fixed internally would be free from objection on the score of exposure, but other difficulties in respect of operation may arise. There is sufficient test data available in connection with doors and shutters for the protection of openings in division walls to enable us to allot to most types of shutter a grade of fire resistance for the protection of window openings in external walls pending actual tests.

201. We have expressed our recommendations for window protection in terms of the following two Grades:

> *Grade D* (1 *hour*) *Protection, e.g.* fire resisting glazing in conjunction with automatic drenchers, both conforming with the rules of the Fire Offices' Committee for the protection of exposed openings; glass bricks in panels not exceeding 5 ft. by 5 ft. with adequate expansion joint; fire resisting shutters or other equivalent protection.
>
> *Grade E* (½ *hour*) *Protection, e.g.* fire resisting glazing conforming to the rules of the Fire Offices' Committee, or other equivalent protection.

Methods of Protecting other External Openings

202. There is sufficient data available, both as the result of experience and test, to enable different types of doors and shutters to be allocated for the purpose of giving the necessary grade of fire protection specified in our recommendations for the protection of openings other than window openings.

Protection of Openings in External Walls of Buildings containing High, Moderate, or Low (Abnormal) Occupancies

It is not intended that the protection suggested in the following paragraphs should apply to lavatory windows and ground floor doorways. (See paragraph 218.)

203. *Openings in External Walls facing Streets.* We have adopted a limit of 40 ft. from an opening in another building as the distance within which protection of openings should be required, and consider that any opening which is within that distance should be provided with Grade E (½ hour) protection (Fig. 1 (a)). Grade D protection will be desirable at distances less than 20 ft., as experience suggests that in these narrow streets fire fighting is for obvious reasons often seriously hindered.

204. It is, of course, impracticable to protect by these methods ground floor display windows which fall within these distances, and we therefore propose that in such cases protection against the risk of spread should be in the form of separation of the show spaces from the remainder of the building. This separation including doors should have a fire resistance of not less than Grade E (½ hour).

205. The severity of the exposure hazard is largely reduced when adjacent windows in two buildings face in the same or almost the same direction, as shown in Fig. 1 (b), but there is still need for protection. The severity of the exposure decreases as the angle between the external walls increases, and whilst requirements laid down above would be appropriate and should be applied when the angle between the faces is less than 90°, they can be considerably relaxed for greater angles. We propose that where the angle is between 90° and 135° only openings within 20 ft. of an opening in another building should be provided with Grade E protection. No openings should be permitted within 3 ft. of the centre line of the junction of the walls in all cases (Figs. 1 (b) and (e)).

206. *Openings in External Walls not facing Streets.* As the exposure hazard due to openings facing on yards or courts is accentuated because of the greater difficulties of access for fire fighting, it is desirable that higher standards of passive defence should be provided, and we recommend the following general standards of protection (see Fig. 1 (c)):

a. No openings should be permitted in an external wall which is less than 10 ft. from an external wall of another building.

b. Openings which are less than 20 ft. from an opening in the external wall of another building should be provided with protection affording Grade D fire resistance.

c. Openings which are not less than 20 ft. but less than 50 ft. from an opening in an external wall of another building should be provided with protection affording Grade E fire resistance.

207. There are, again, certain situations in which the proposals made in paragraph 206 could be relaxed. When two external walls conjoin, openings may be made up to 3 ft. from the junction of the walls, and the following protection provided:

a. Where the angle between the walls measured externally is not less than 90° but less than 135°, protection should be provided at one-half the distances given in paragraphs 206 (b) and (c), (Fig. 1 (d)).

b. Where the angle between the walls is not less than 135° the openings need not be protected (Fig. 1 (e)).

Protection of Openings in External Walls of Buildings containing Low (Normal) Fire Load Occupancies

208. Because of the much reduced risk arising from an outbreak of fire in occupancies of low normal fire load, considerable relaxation of the foregoing proposals is possible, and we consider that the following standards are adequate (see Fig. 2).

a. *Openings in External Walls facing Streets.* It is recommended that protection affording Grade E fire resistance should be provided when an opening in an external wall is less than 20 ft. from an opening in an external wall of buildings of high, moderate, or low (abnormal) fire load occupancy (Fig. 2 (a)).

b. *Openings in External Walls not facing Streets*

   i. Openings less than 10 ft. from an opening in the external wall of a building containing an occupancy of low normal fire load should be provided with Grade E protection (Fig. 2 (c)).

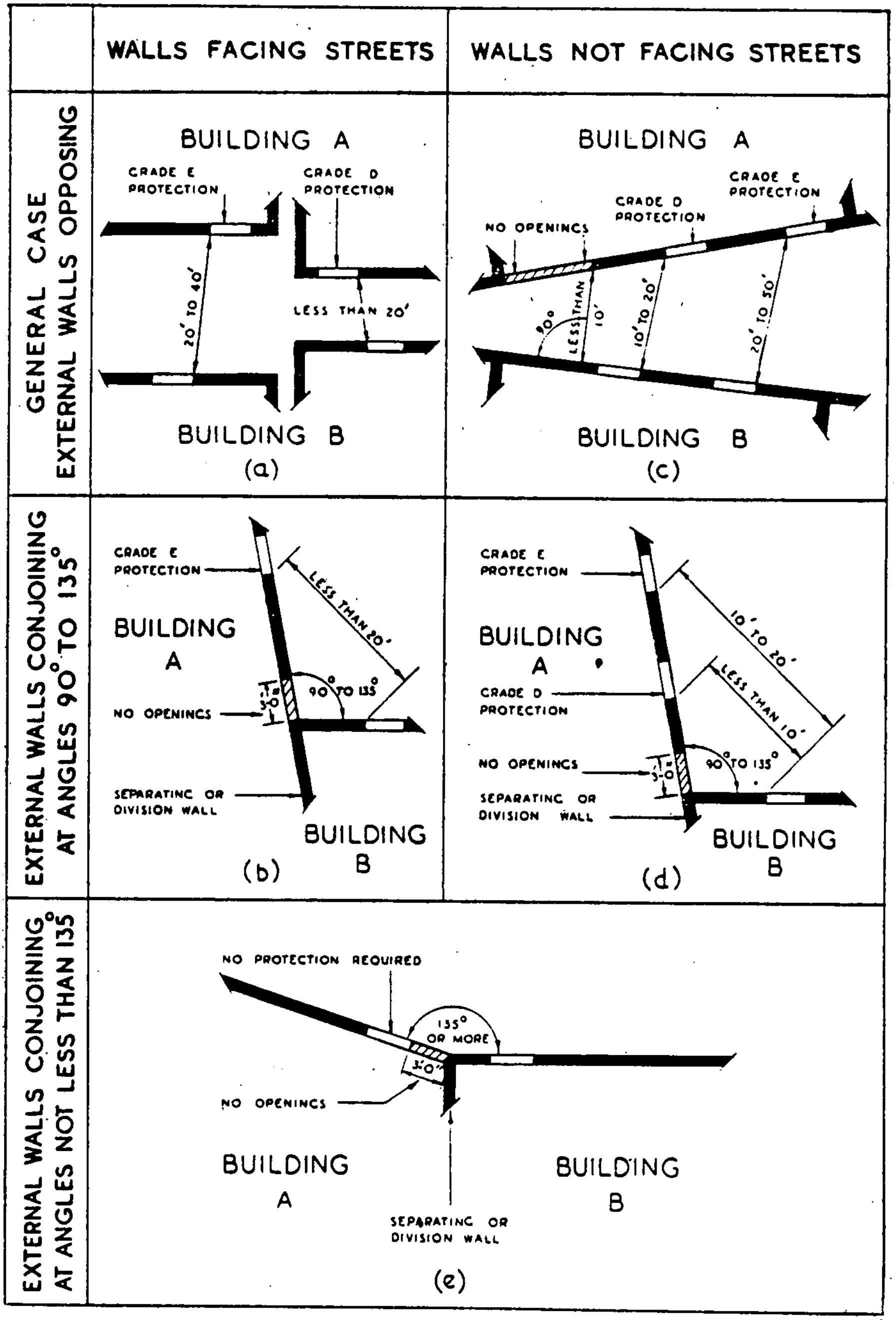

Fig. 1. PROTECTION OF OPENINGS IN EXTERNAL WALLS
BUILDINGS (OR DIVISIONS) OF HIGH, MODERATE, OR LOW (ABNORMAL) FIRE LOAD OCCUPANCY

Building A is the Exposed Building Building B is the Exposing Building

ii. Openings less than 10 ft. from an opening in the external wall of a building containing an occupancy of high, moderate, or low abnormal fire load should be provided with Grade D protection (Fig. 2 (d)).

Note. (ii) would be operative only in the case where an existing building has openings within 10 ft. of the exposed building. (See para. 206 a.)

iii. Openings not less than 10 ft. but less than 30 ft. from an opening in an external wall of a building containing an occupancy of high, moderate, or low (abnormal) fire load should be provided with Grade E protection (Fig. 2 (d)).

209. Relaxation of the recommendations made in paragraph 208 is proposed where the external walls conjoin, but in no case should an opening be closer than 3 ft. to the junction of the walls. In case (a) above, where the angle is not less than 90° but less than 135°, Grade E protection should be provided for any opening which is less than 10 ft. from an opening in the adjoining wall (Fig. 2 (b)), and similarly in case (b) above, Grade E protection should be provided when the distance is less than 15 ft. (Fig. 2 (e)). In either case, when the angle is 135° or more, no protection is proposed (Fig. 2 (f)).

Openings in External Walls exposed to Combustible Roofs, etc., or to Lower Buildings

210. The numerous instances which occur in practice, where windows or other openings overlook a combustible roof of a lower building, or openings in a fire resisting roof, etc., present considerable exposure risks, and protection of the openings is desirable. In general it is sufficient to protect openings which are within 50 ft. of the exposing roof. The exposed openings should be provided with Grade D protection if within 20 ft. of the exposing roof, or Grade E if the distance is more than 20 ft. but less than 50 ft. If the exposure is due solely to openings in a fire resisting roof, protection required for the latter reduces the hazard and we would regard corresponding protection at one-half of these distances as sufficient (paragraph 215).

211. Experience has shown that upper storeys of high buildings are vulnerable to fire in lower storeys of adjacent buildings at distances much greater than would normally be anticipated, and special consideration is desirable where the exposed windows are beyond the normal range of fire hoses.

This effect may be explained with the help of Fig. 3. If A is the exposing building on fire and B the high exposed building spaced sufficiently far from A to prevent normal spread, it has been found that whilst the lower storeys of B are unaffected, the upper storeys may nevertheless be ignited. This is attributable to the upward drift of hot gases from the fire at an angle which will of course be influenced by wind conditions striking the upper storeys of B. We have considered whether we could formulate recommendations to cover such risks, but it was not found possible to frame them in a simple manner so that they would apply only in those cases where protection is desirable. We would, however, draw special attention to the risk, which, it may be noted, is accentuated because of the difficulty of fire fighting at considerable heights, in order that architects may be aware of the need for protection where the condition arises.

Openings situated Vertically Above One Another in Buildings of Fully Protected Construction

212. If the storeys of a building are separated at all points from one another by fire resisting construction of a sufficient grade to resist a complete burn-out, there still remains risk of spread of fire between storeys via windows. If on account of exposure from other buildings it is necessary to protect these windows, an adequate degree of protection against the risk of spread from storey to storey

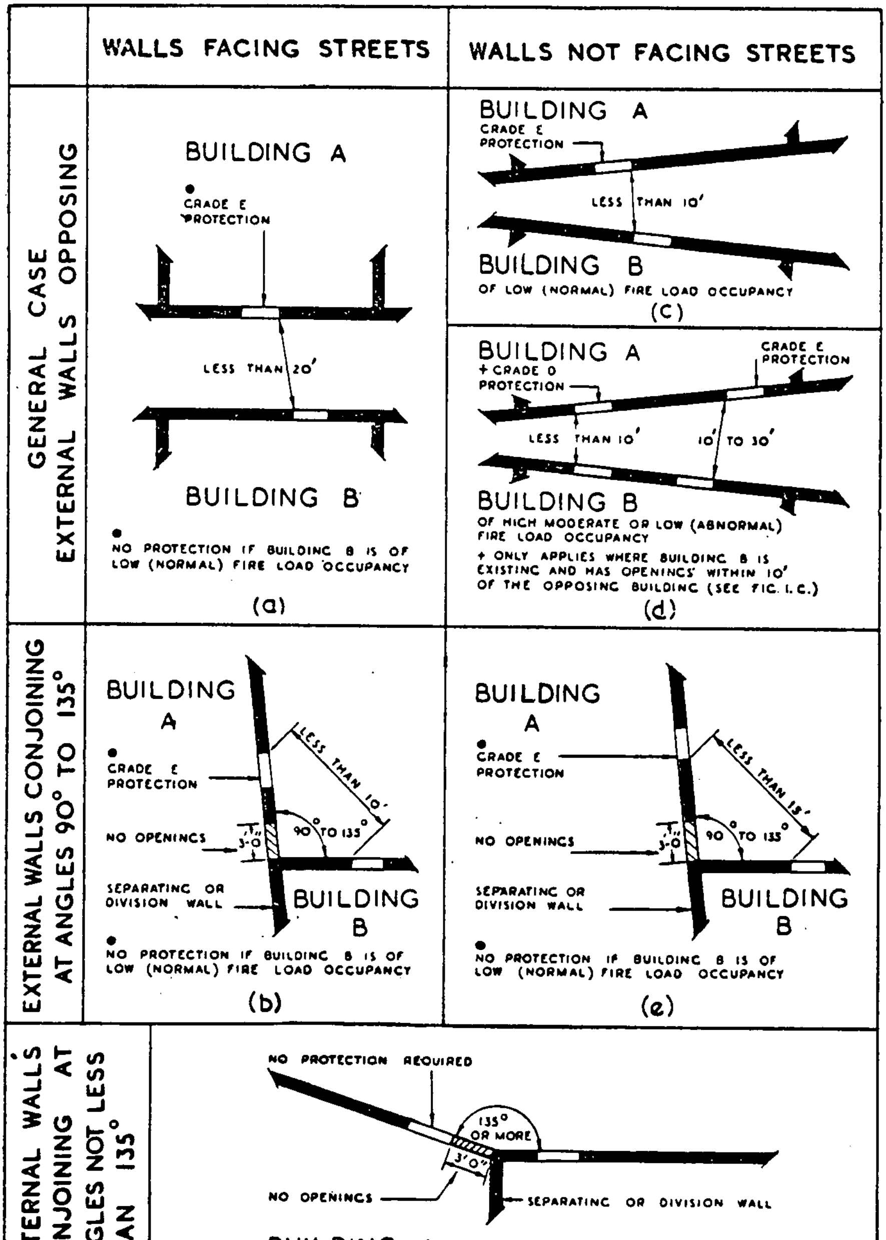

Fig. 2. PROTECTION OF OPENINGS IN EXTERNAL WALLS

BUILDINGS (OR DIVISIONS) OF LOW (NORMAL) FIRE LOAD OCCUPANCY

Building A is the Exposed Building Building B is the Exposing Building is assured, but where such protection is not required considerable risk is entailed. A large proportion of window openings markedly accentuates the risk and adds to difficulties of fire fighting. With average amounts of window openings we felt that it would be onerous to demand protection in all cases. A reasonable degree of protection could be obtained by providing at least 3 ft. of construction (of which at least 2 ft. should be above floor level) of the same grade of fire resistance as the walls, between the lintel of the lower window and sill of the one above. This would, in addition, provide the pitching for firemen's ladders and for emergency rescue. In those cases where there is no access for firemen, *e.g.* in light wells, it is considered necessary to protect windows in all cases to Grade E fire resistance. In the case of the bulk storage buildings it would seem that, because of the relatively limited demand for window openings, no undue hardship would be entailed if all windows in warehouse buildings with fire resisting floors were provided with Grade E protection, unless of course a higher grade of resistance is demanded for other reasons. In other cases where fire resisting glazing can be used, improved security will naturally result.

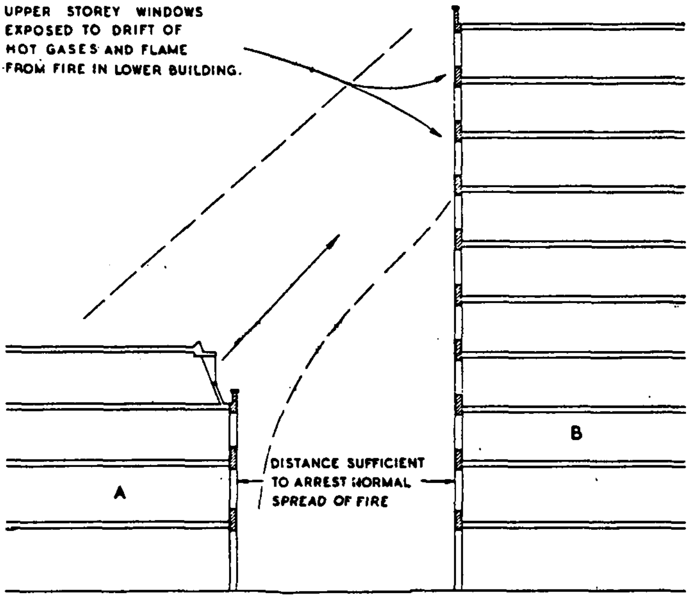

Fig. 3. EXPOSURE HAZARD TO HIGH BUILDINGS

Special Cases

213. *Buildings with more than 50 per cent Window Opening.* We have now to consider the special case of buildings which may be of fire resisting construction as regards structural frame, floors, etc., but in which the external walls are largely replaced by glass. They present special hazards both in respect of exit and entry of fire, spread of fire from storey to storey, and in respect of fire fighting. The proposal for baffle walls in paragraph 212 will limit the amount of openings in storeys of average height, but more than 50 per cent is possible with greater storey heights. We therefore suggest that if the proportion of window opening exceeds 50 per cent in any external elevation, the elevation should be at least 60 ft. (measured at right angles to the elevation) from any other building.

214. *Open-sided Buildings.* The conditions do not differ materially from those obtaining above, and we propose the same separation.

Glazed Openings in Roofs

215. These present a similar and, under certain conditions, a somewhat greater hazard than windows, and we propose that, where the opening is within 50 ft. of a roof of combustible construction or of an opening in the external wall or roof of another building, it would be desirable to protect it with Grade E protection.

SPRINKLERS

216. Essentially sprinklers are designed to extinguish a fire in a building at its inception. Many instances have occurred during war-time where sprinkler heads in exposed buildings have been actuated by radiant heat from the exposing building and have effectively prevented spread of fire. In view of the water damage which may be caused to stocks in the exposed building, preferable though it may be to possibly more extensive damage by fire, it is considered that, from the standpoint of protection against exposure, sprinklers should be regarded as the last line of defence; and that the safeguards of the kind described above should be adopted in order to minimize, as far as possible, any damage by water or fire inside the exposed building.

FIRE FIGHTING

217. In arriving at our recommendations we have assumed broadly that fire fighting forces will be available of at least equivalent efficiency to those which existed before the war.

APPLICATION OF RECOMMENDATIONS

218. In principle the recommendations above should apply to all buildings irrespective of size, for the risk of spread of fire *into* a building is in theory almost independent of the size of the building, and hence the measures which should be taken to minimize that risk should be independent of its size. However, as the resultant fire in the small building will not present the same risk as a large fire, there is excuse for relaxing the precautions. Accordingly we suggest that the provisions recommended in paragraphs 203–215 should apply only to buildings exceeding 100,000 cu. ft. in capacity, and that for smaller buildings the protection should be required only at one-half the distances. As regards separation of ground floor display windows, this is not, of course, considered necessary in shops where the materials displayed are not readily ignitible, *e.g.* fishmongers, grocers, etc., nor in buildings of a lower grade than Type 4.

It is realized that the strict interpretation of some of these recommendations might work to the disadvantage of an existing or prospective building. We have not thought it our duty to elucidate the position, but feel we should draw attention to its existence. It will be noted that we have taken the distance between buildings or openings as the basis for measurement. In formulating clauses for inclusion in rules or regulations it will be necessary to adopt as a basis the distance from some boundary, *e.g.* the boundary of a site, or the street.

SUMMARY OF RECOMMENDATIONS IN SECTION I

GRADING OF OCCUPANCIES

GENERAL GRADING

219. For the purpose of defining requirements for fire precautions in buildings (except means of escape), occupancies should be graded on the basis of fire load as follows:

1. *Occupancies of Low Fire Load.* The fire load of an occupancy is described as low if it does not exceed an average of 100,000 B.Th.U's./sq. ft. of net floor area of any compartment, nor an average of 200,000 B.Th.U's./sq. ft. on limited isolated areas, provided that storage of combustible material necessary to the occupancy may be allowed to a limited extent if separated from the remainder and enclosed by fire resisting construction of an appropriate grade.

2. *Occupancies of Moderate Fire Load.* The fire load of an occupancy is described as moderate if it exceeds an average of 100,000 B.Th.U's./sq. ft., but does not exceed an average of 200,000 B.Th.U's./sq. ft. of net floor area of any compartment, nor an average of 400,000 B.Th.U's./sq. ft. on limited isolated areas, provided that storage of combustible material necessary to the occupancy may be allowed to a limited extent if separated from the remainder and enclosed by fire resisting construction of an appropriate grade.

3. *Occupancies of High Fire Load.* The fire load of an occupancy is described as high if it exceeds an average of 200,000 B.Th.U's./sq. ft. but does not exceed an average of 400,000 B.Th.U's./sq. ft. of net floor area of any compartment, nor an average of 800,000 B.Th.U's./sq. ft. on limited isolated areas.

NORMAL AND ABNORMAL OCCUPANCIES

220. If the fire load presents no special features it should be described as a normal fire load, but if (a) the materials constituting the combustible content or any substantial part are included in one or other of the categories given in Appendix I, or (b) the nature of the trade or manufacture be such as to increase the fire probability, cause the rapid burning of the contents, hinder fire fighting by the emission of poisonous or noxious fumes, or in any way accentuate the fire hazard, the occupancy should be graded as "abnormal." It should not, however, be regarded as necessary to grade an occupancy as abnormal, if a limited area of an otherwise normal occupancy is used for the purpose of carrying on an abnormal process in connection with the trade of the occupancy, provided that such area is separated from the remainder and enclosed by fire resisting construction of the appropriate grade.

APPLICATION

221. The definitions set out in paragraphs 219 and 220 might be used when necessary as a fundamental basis for determining the grading of an occupancy, but for general purposes the gradings in Table 1 should be adopted.

SPECIAL OCCUPANCIES

222. We propose that certain occupancies should be excluded from the general grading above on account of:

a. The fire load being in excess of the maximum value for high fire loads; or

b. Certain unusual features which warrant special precautions owing to very high fire risk, or the specially low fire risk presented which may warrant relaxation of precautions.

Such occupancies are described as "special occupancies" and each will require separate consideration.

GRADING OF BUILDINGS ACCORDING TO FIRE RESISTANCE

223. For the purpose of grading buildings according to their resistance to the effects of fire, seven types of construction are proposed as follows:

Types 1, 2, and 3. INCOMBUSTIBLE FIRE RESISTING CONSTRUCTION: fully or partially protected according to the fire load of the occupancy.

Type 4. FIRE RESISTING CONSTRUCTION: internal construction not necessarily incombustible and may therefore include combustible floors and roof.

Type 5. EXTERNALLY PROTECTED CONSTRUCTION

Type 6. UNPROTECTED INCOMBUSTIBLE CONSTRUCTION

Type 7. COMBUSTIBLE CONSTRUCTION

TYPE 1 CONSTRUCTION

224. For grading as Type 1 construction, the structural elements of a building should have grades of fire resistance not less than those shown in the appropriate section of Table 5 and be wholly of incombustible material except that combustible material may be used for decorative linings and finishes, floor surfacing, doors, window frames, and similar parts.

Type 1 construction may be described as fully protected construction in relation to any occupancy of low, moderate, or high fire load.

TYPE 2 CONSTRUCTION

225. For grading as Type 2 construction, the building should conform with requirements corresponding to those set out above for Type 1 as regards the fire resistance gradings of structural elements according to the appropriate section of Table 5, incombustibility of the elements, and the use of combustible material.

Type 2 construction may be described as fully protected construction in relation to any occupancy of low or moderate fire load, or partially protected in relation to any occupancy of high fire load.

TYPE 3 CONSTRUCTION

226. For grading as Type 3 construction, requirements corresponding to those set out in Types 1 and 2 should apply.

Type 3 construction may be described as fully protected only in relation to occupancies of low fire load, and partially protected in relation to occupancies of moderate and high fire load.

TYPE 4 CONSTRUCTION

227. For a building to be graded as Type 4 construction, the elements of structure should have grades of fire resistance not less than those given in Table 5. Roofs, floors, and other internal construction may be of combustible material if conforming with those grades of fire resistance. Type 4 construction may be described as partially protected in relation to any occupancy of low, moderate, or high fire load.

TYPE 5 CONSTRUCTION—EXTERNALLY PROTECTED CONSTRUCTION

228. For a building to be graded as Type 5 construction, its external walls, division walls, and party walls should be of incombustible material and have grades of fire resistance not less than those given in the appropriate section of Table 5. The internal construction need not conform to any standards of fire resistance and need not be of incombustible material.

TYPE 6 CONSTRUCTION—UNPROTECTED INCOMBUSTIBLE CONSTRUCTION

229. For a building to be graded as Type 6 construction, every element of structure should be of incombustible material but, except for the separating and division walls, need not conform to any grades of fire resistance. Combustible materials may be used for wall and roof linings, doors, skirtings, and other trim.

TYPE 7 CONSTRUCTION—COMBUSTIBLE CONSTRUCTION

230. A building will be considered to be of Type 7 construction if its external walls, floors, and roofs are of combustible material. Separating and division walls should be of incombustible material and have grades of fire resistance not less than those laid down in the appropriate section of Table 5.

FIRE RESISTANCE OF ELEMENTS OF STRUCTURE IN BASEMENTS

231. In the case of buildings of Types 1, 2, 3, and 4 construction, the fire resistance of elements of structure in basements and sub-basements should be not less than 2 hours in buildings containing occupancies of low fire load and not less than 4 hours in buildings containing any other fire load.

REQUIREMENTS FOR GRADED TYPES

SUBDIVISION OF BUILDINGS

232. Buildings containing certain grades of occupancy and which exceed a size determined by their occupancy and type of construction, should be divided into divisions and/or compartments, by walls, or by walls and floors of an appropriate grade of fire resistance, as given in Table 5.

a. *Protection of Openings.* All openings in walls forming fire resisting separation between divisions or compartments should be protected by doors and shutters having a similar grade of fire resistance to that of the wall. It is desirable that such openings should be limited in size and number, and whilst as a basis the aggregate width of any such openings in any wall of a storey should not exceed half the length of the wall, the conditions pertaining in each case should be taken into account in deciding the allowable extent.

b. *Protection of Shafts.* In buildings of Types 1–4 construction all shafts should be enclosed by walls having a fire resistance not less than that given in Table 9, and openings in the walls should be protected by doors of a corresponding grade of fire resistance.

Height, Floor Area, and Cubic Capacity

LIMITATION OF HEIGHT OF BUILDINGS

233. The heights of buildings should not generally exceed the limits given in Tables 7a, 7b, 7c, and 8 subject to a tolerance of +5 ft.

FLOOR AREAS AND CUBIC CAPACITY OF BUILDINGS, DIVISIONS, OR COMPARTMENTS

234. The floor area and cubic capacity of each compartment of a building of

fully protected construction should not exceed the limits given in the first parts of Tables 7a, 7b, 7c, and in Table 8, except that:

a. The floor area and cubic capacity of any sub-basement should not exceed 5000 sq. ft. or 62,500 cu. ft. respectively, or 20,000 sq. ft. and 250,000 cu. ft. respectively when the building is equipped with an approved sprinkler installation.

b. The floor area and cubic capacity of any compartment the floor of which is at a height of more than 100 ft. from street level, should not exceed one-half of the values recommended in the Tables.

235. The cubic capacity of a building or of each division of a building not of fully protected construction should not exceed the limits given in the second parts of Tables 7a, 7b, 7c, and in Table 8, except that the floor area and cubic capacity of any sub-basement should not exceed 3750 sq. ft. and 47,000 cu. ft., or double these values if the building is equipped with an approved sprinkler installation.

ADDITIONAL PRECAUTIONS IN LARGE BUILDINGS

236. Every building or division except those containing occupancies of low normal fire load should be equipped with an approved sprinkler installation if the floor area exceed 10,000 sq. ft.; or with an approved fire alarm system if the floor area does not exceed 10,000 sq. ft. but the cubic capacity of the whole building or division exceeds 250,000 cu. ft.

ACCESSIBILITY OF BUILDINGS AND DIVISIONS OF BUILDINGS

237. Every building or division should have a portion of its perimeter abutting on a street or streets, or unobstructed open space on the same plot and with access of sufficient width and height for mobile fire fighting appliances from a street. Where the cubic capacity of the building or division exceeds 100,000 cu. ft., the portion so abutting should be at least 8 ft. per 1000 sq. ft. of floor area and the street or streets should be not less than 40 ft. wide.

238. Every external wall of a building or division of a building exceeding 40 ft. in height which abuts on a street (or open space) as recommended in paragraph 237, should be located so as to be at all points within a plane inclined at an angle of not less than $63\frac{1}{2}^\circ$ to the horizontal from the building line on the opposite side of the street at pavement level. Set-backs of the external wall should be provided above a height of 100 ft. in the form of terraces about 6 ft. wide for use by firemen. They should be located at each floor level, and have suitable access from staircases. No set-backs of the external wall need be required above the height of 100 ft. where the occupancy is of low normal fire load.

BUILDINGS EXCEEDING PROPOSED LIMITS OF FLOOR AREA, CUBIC CAPACITY, AND HEIGHT

239. Buildings (divisions or compartments) having floor areas, cubic capacities, or heights greater than those limits set out in Tables 7 and 8 may be erected where the siting, access, planning and other relevant factors justify their construction. In such cases the following principles should be followed where appropriate:

a. Where very large areas are allowed the number of storeys should be kept to a minimum.

b. Where heights in excess of those set out in Tables 7 and 8 are necessary the floor areas of the compartments should be kept as small as possible.

c. The maximum possible degree of isolation from other buildings should be provided.

d. Any part of the building used for storage, or for an abnormal occupancy or any portion offering a higher risk than the general risk, should be separated from the remainder of the building by incombustible fire resisting construction of suitable grade (but in no case less than 1 hour).

e. If of more than one storey, the building should be of fully protected construction according to the fire load.

f. If single storey only, the building should be of incombustible construction, and the use of combustible material, *e.g.* in linings, be reduced to a minimum.

g. Suitable automatic sprinkler equipment should be installed where desirable.

h. The recommendations for fire fighting equipment applicable to floor areas greater than 10,000 sq. ft. area or heights in excess of 100 ft. should apply. Special water supplies should be installed where necessary.

j. Additional reasonable safeguards to reduce the fire risk in the special circumstances of each particular case should be required.

k. The staff of the occupier should include trained personnel always to be available so as to attack a fire immediately, and to ensure the satisfactory maintenance and operation of all fire protection apparatus and fire extinguishing equipment.

SMOKE EXTRACTS

240. Basement exceeding 10,000 sq. ft. in area and not ventilated naturally, and similar sub-basements exceeding 2500 sq. ft. in area, should be provided with adequate smoke extracts.

PROTECTION AGAINST EXPOSURE HAZARD

241. For the purpose of these recommendations the distance between walls of the same construction or between openings has been taken as the basis for measurement. In formulating specific clauses for inclusion in rules or regulations, it may be necessary to adopt as a basis the distance from some boundary, *e.g.* the boundary of the site, or the street. It is thought that the distances given will provide sufficient information for the purpose.

LOCATION OF EXTERNAL WALLS

242. *Incombustible Walls*

a. The location of external walls of not less than 2 hours fire resistance in relation to other buildings, need not be restricted.

b. External walls of less than 2 hours but not less than ½ hour fire resistance should be erected at distances from other buildings not less than:

(i) the minimum distance at which window protection of the same grade of fire resistance would be required, or

(ii) three-quarters of the height of the wall whichever is the greater.

If, however, the building contains an occupancy of low normal fire load and the wall is of framed construction not exceeding 50 ft. in height, and has a fire resistance of not less than 1 hour, the distance from the external wall of any other building need not exceed 10 ft.

c. External walls of less than ½ hour fire resistance should be erected at a distance from other buildings not less than:

(i) the minimum distance at which window protection is not required, or

(ii) three-quarters of the height of the wall, whichever is the greater.

d. Recommendations (b) and (c) need not apply (i) to external walls of buildings which do not exceed 20,000 cu. ft. in capacity; (ii) if the building is separated from another building by an imperforate wall of at least 4 hours fire resistance.

Walls with Combustible External Covering

243. We recommend the retention of the requirements laid down in the Model Bye-laws of the Ministry of Health (see Appendix V), subject to there being no increased use of combustible materials for external walls. Proposals for the erection in any one locality of numbers of buildings having combustible external covering should be considered separately.

Protection of Openings in External Walls

APPLICATION OF RECOMMENDATIONS

244. The following recommendations are intended to apply to openings in the external walls of buildings or divisions exceeding 100,000 cu. ft. in capacity. The same principles should also apply to buildings and divisions of lesser cubical extent, but the distances at which protection is recommended may be reduced by *one-half*. The recommendations do not apply to lavatory windows and ground floor doorways.

BUILDINGS (OR DIVISIONS) CONTAINING OCCUPANCIES OF HIGH, MODERATE, OR LOW (ABNORMAL) FIRE LOAD. (SEE FIG. 1)

245. 1. *Openings facing Streets*

Every opening in an external wall, other than show windows in the ground storey, should be provided with ½ hour (Grade E) protection where the distance from an opening in the external wall of another building is less than 40 ft., and Grade D protection if the distance is less than 20 ft.

2. *Openings not facing Streets*

a. No openings should be permitted in an external wall which is less than 10 ft. from an external wall of another building.

b. Openings which are less than 20 ft. from an opening in the external wall of another building should be provided with protection affording 1 hour (Grade D) fire resistance.

c. Openings which are not less than 20 ft. but less than 50 ft. from an opening in an external wall of another building should be provided with protection affording ½ hour (Grade E) fire resistance.

Where, however, the external walls of two buildings conjoin at an angle of not less than 90°, openings may be made up to 3 ft. from the junction of the walls, and protection need only be provided where the angle is less than 135° and at half the distances specified in (1) and (2).

BUILDINGS (OR DIVISIONS) CONTAINING OCCUPANCIES OF LOW (NORMAL) FIRE LOAD (SEE FIG. 2)

246. 1. *Openings facing Streets*

Every opening in an external wall, other than show windows in the ground storey, should be provided with Grade E protection if the distance from an opening in an external wall of a building of high, moderate, or low abnormal occupancy is less than 20 ft.

2. *Openings not facing Streets*

a. Openings less than 10 ft. from an opening in the external wall of another building of low (normal) fire load occupancy should be provided with protection affording ½ hour (Grade E) fire resistance.

b. Openings not less than 10 ft. but less than 30 ft. from an opening in the external wall of a building of high, moderate, or low (abnormal) fire load occupancy should be provided with protection affording ½ hour (Grade E) fire resistance.

c. Openings less than 10 ft. from an opening in the external wall of a building of high, moderate, or low (abnormal) fire load occupancy, should be provided with protection affording 1 hour (Grade D) fire resistance. (Applicable only if the exposing building is existing and has openings within 10 ft. of the exposed building.)

Where, however, the external walls of two buildings conjoin at an angle not less than 90°, openings may be made up to 3 ft. from the junction of the walls, and protection need be provided only in the case of (1) and (2b) above, where the angle is less than 135° and at half the distances specified.

Ground Storey Show Windows

247. Except where the goods displayed are not easily ignited, ground storey show windows in buildings of Types 1, 2, 3, or 4 construction should be completely separated from the remainder of the building by incombustible construction of not less than ½ hour (Grade E) fire resistance, and any doors between the interior of the building and the show area should be self-closing and of the same grade of fire resistance.

OPENINGS IN EXTERNAL WALLS SUBJECT TO EXPOSURE FROM ADJACENT ROOFS

248. a. Every opening in an external wall of a building situated above a combustible roof, or an incombustible roof not of a required grade of fire resistance of another building or another compartment of the same building, should be provided with 1 hour (Grade D) protection if within 20 ft. of the roof, or with ½ hour (Grade E) protection if within 50 ft. of the roof.

b. Every opening in an external wall of a building situated above an opening in a roof of a required grade of resistance, of another building or another compartment of the same building, should be provided with 1 hour (Grade D) protection if within 10 ft. of the opening in the roof or with ½ hour (Grade E) protection if within 25 ft. of the opening in the roof.

OPENINGS SITUATED VERTICALLY ABOVE ONE ANOTHER IN THE SAME BUILDING

249. In a building of either Type 1, 2, or 3 construction:

a. Every window opening of a light well or court not externally accessible to mobile fire fighting appliances should be provided with ½ hour (Grade E) protection.

b. Every window opening situated vertically above other window openings should be separated by at least 3 ft. of wall construction of the required grade of fire resistance.

WAREHOUSE BUILDINGS

250. Openings in the external walls of a building of Type 1 or Type 2 construction containing an occupancy of high fire load should be provided with ½ hour (Grade E) protection unless 1 hour (Grade D) protection is otherwise required.

EXTERNAL WALLS WITH MORE THAN 50 PER CENT WINDOW OR OTHER OPENINGS

251. If the proportion of window openings above the ground storey exceeds 50 per cent of the area of the elevation, the wall should be at least 60 ft. (measured at right angles to the elevation) from every other building.

Protection of Roofs and Openings in Roofs

Fire-retardant Roof Coverings

252. The roof of every building should be provided with a fire-retardant roof covering unless the building is suitably separated from every other building. The following materials can be regarded as fire-retardant when used as indicated:

a. Clay, concrete, asbestos cement, stone or glass tiles.

b. Natural or asbestos cement slates.

c. Asphalt mastic.

d. Lead, copper, zinc, aluminium.

e. Asbestos cement sheeting, wired glass, steel sheeting galvanized or protected with bituminous material with or without mineral fibre.

f. Bituminous roofing felt made with animal or vegetable fibre covered with incombustible material of suitable thickness.

g. Bituminous roofing felt made with animal or vegetable fibre on an incombustible base.

h. Bituminous roofing felt made with mineral fibre.

Non-Fire-Retardant Roof Coverings

253. The following materials are classified as non-fire-retardant: thatch, bituminous felt sheeting (not conforming with (f), (g), and (h) above), wood shingles, plywood. We recommend that the separation set out in Model Bye-laws of the Ministry of Health applicable to roof coverings of this kind should be retained and in addition that the cubic capacity of buildings so covered should not exceed 36,000 cu. ft. Use of wood shingles should not be permitted, except on church steeples, etc., and on isolated buildings.

Glazed Openings in Roofs

254. Glazed openings in a roof covered with fire-retardant material should be provided with ½ hour (Grade E) protection if they are within 50 ft. of a roof of combustible construction or of an opening in the external wall or roof of another building.

SECTION II

ONE- AND TWO-STOREY DWELLINGS

GENERAL

255. In the foregoing treatment of fire grading we have dealt with occupancies in grades according to fire loads and have considered fire precautions in relation to each grade. This method is necessary to avoid repetition and undue bulk. The special problem presented by a very large number of dwelling houses and the difference in character of the fire risk presented by a number of small units, justifies independent consideration. Accordingly, in this section of our Report, we treat the fire risk in the dwelling house in greater detail, and have found it convenient to approach it in a somewhat different manner from that adopted in Section I. Although this necessitates repetition of some aspects, we feel that the predominating importance of the small house fully warrants presentation of the subject in a section complete in itself, especially on account of the proposals to use types of construction which are fundamentally different from the traditional

brick house. The section relates only to small one- or two-storey houses for one or two families; buildings of greater size intended as multiple family dwellings fall into the general grading.

256. In our discussion we shall again, as far as possible, consider the problem by reference to standards instead of actual materials or systems of construction. The proposed standards will therefore be applicable to all types of construction, and in particular to those which are commonly referred to as "prefabricated," which we have broadly interpreted to mean light structures forming the external and internal construction, mainly constructed in the factory, delivered to the site in large units and erected with a minimum of site work. In recommending these standards we have taken into account the conditions which are likely to persist in the immediate post-war period.

THE NORMAL HOUSE

257. The precautions taken against fire hazard in houses built with brick or stone walls, timber floors with lath and plaster ceilings, brick, block, or lath and plaster partitions, 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 separating wall need not now be carried through the roof in all cases, while others have been added from time to time, *e.g.* in 1938 further measures dealing with hearths and flues were introduced into the London County Council and Ministry of Health Bye-laws. As a result, the house of normal construction is regarded as affording reasonable protection against fire, even though occasionally the whole structure may be gutted, leaving only the external walls, separating wall, and some partitions standing.

258. It does not follow, however, that normal construction can be adopted in all respects as a standard on which to base consideration of the adequacy of the fire protection given by alternative forms of house construction proposed for the post-war period. In some respects, requirements for purposes other than fire protection automatically ensure a standard of protection well above what is really required, *e.g.* the 9-in. brick wall is required on the grounds of stability, weather resistance, etc. For that reason alone, therefore, closer examination of what are the fundamental requirements on fire protection in dwellings is needed, if justice is to be done to alternative forms. Quite apart from that, it may well be that there are forms of protection provided by normal construction which are so inherent as to tend to cause them to be forgotten. This emphasizes the desirability of reviewing from first principles what are the real needs, and this is most easily done by considering separately the hazards against which protection has to be provided.

NATURE OF HAZARDS

259. First, we shall consider the question in terms of the personal safety of the occupants; next, the effect of a fire on the house itself, particularly as regards the risk of fire spreading past the separating wall; and finally, whether the house is likely to catch fire easily from an adjacent house, factory, timber yard, motor vehicle, or grass which is on fire, *i.e.* exposure hazard.

PERSONAL HAZARD

260. The essential requirement in connection with the risk which the construction presents to the occupants, the "personal hazard," is that the structure should be such that flame and smoke will not spread so rapidly that the occupants have insufficient time to escape should fire occur.

It is well to emphasize that loss of life in house fires is mainly due to smoke and hot gases being inhaled by occupants before actual flaming has developed to a serious degree within the room or part occupied, and it is appreciated that much of the danger arises from unrestricted spread of smoke and hot gases through doorways. As it is virtually impossible to ensure that doors are kept closed, the danger from that source will remain, and the most that can be done is to ensure that the construction does not increase the danger to a serious degree as compared with the normal house.

261. In order to reduce the personal hazard it is necessary that:

1. The materials which are exposed to possible ignition, *e.g.* wall linings, should not easily ignite, nor should the fire spread rapidly over the surface of the material. Furniture and furnishings are often the most easily ignited materials in a house, but the risk from this source may be assumed to be the same for all forms of house construction.
2. The fire must not spread rapidly from one room to another through the upper floor, partitions between rooms, and particularly between rooms and passages and staircase, *i.e.* the building elements must have adequate fire resistance as defined in *B.S.* 476.
3. Consideration must be given to means of escape, especially from the upper storey.

Whilst fire fighting is also an important factor, it is considered that, from the present standpoint, the structural measures should be considered without respect to this feature, any safeguards which result from fire fighting being regarded as an additional contribution to safety.

EASE OF IGNITION AND SURFACE SPREAD

262. Questions relating to ease of ignition and surface spread arise mainly in connection with the use of combustible wall and ceiling linings, and the danger therefrom can best be appreciated by reference to examples. The ease of ignition and rate of spread of fire over the surfaces of certain types of wall boards are such that the occupants of a room might be overcome before they are able to escape. At the other extreme a surface of concrete or brick would present no such risk. Intermediately there will be a gradation of risk, depending on the type of surface. 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. Thus people in a room where the fire starts can generally escape through the door by moving close to the wall surface when this is of incombustible material. This is less possible where the wall surface is combustible. Thus, of the types of construction in common use already, that involving untreated fibreboard would approach the danger level; such surfaces are easily ignited, and spread of fire may be rapid. Instances are known where, within a minute or two of the outbreak, escape was seriously prejudiced.

263. The risk which can be permitted will depend largely on the situation. In passages and on staircases less risk can be tolerated than in a room, and accordingly the exposed surfaces of materials used in the former situations should be less susceptible to fire.

264. A test has recently been developed by the Building Research Station and is now incorporated in *B.S.* 476 whereby the susceptibility to fire of various types of wall surfaces can be determined in terms of the rate of spread of fire. Materials may thus be classified into groups on that basis, and four groups are specified. The physical criterion which determines the classification of a surface is the distance which flame spreads over the surface under the test conditions. A description of the test and the conditions of testing, together with the classification, are given in Appendix VII. On the basis of test results and of experience of materials

in practice, an indication is given in Table 10 of the situation in which materials falling into the various classes should be used in house construction. It must be emphasized that the test is solely a means for classifying materials, and the rates of spread of flame in an actual fire will vary according to fire conditions.

Where framed walls, partitions, or floors are lined with combustible material it is recommended that the surfaces on both sides of the material should conform to the appropriate class set out in Table 10, because there is considerable danger from fire starting and rapidly spreading within the concealed cavity unknown to the occupants whose escape may be prejudiced thereby.

TABLE 10. RECOMMENDED USES FOR WALL AND CEILING LININGS[1]

CLASS 1	CLASS 2	CLASS 3
May be used in any situation.	May be used in any situation, except on walls and ceilings of staircases and passages.	Should be used only in living rooms and bedrooms but not rooms in the roof, and only as a lining to solid walls and partitions. Not on staircases or corridors.

265. The use of Class 4 materials needs special consideration because it includes untreated wood fibreboards. This material has been very widely used in the past, especially as ceiling linings, but; as mentioned in paragraph 262, unrestricted use of materials of this class in rooms has caused some concern. There is, however, no evidence to show that their use as ceiling linings alone is attended with the same degree of risk, for when used on ceilings they are out of reach of a number of possible sources of ignition. We consider that, provided the ceiling is at least 7 ft. 6 in. from the upper surface of the floor below, and the wall surfaces conform with requirements for Class 1, the wood fibreboards may be used except in kitchens, passages, and staircases. Some types, however, contain bitumen, and in addition to the risk from spread of fire emit dense smoke on burning, which seriously hinders escape and fire attack. Such materials should be excluded under these conditions.

FIRE RESISTANCE REQUIREMENTS IN RELATION TO PERSONAL HAZARD

266. Apart from the need for adequate provision against rapid spread of fire across the surface of walls and ceilings, the elements of structure should be capable of containing an outbreak of fire within the room in which it starts until the occupants of other rooms can make good their escape. The distinction between the two requirements should be fully appreciated.

The worst condition arises at night-time when the occupants are asleep, and having regard to the fact that they may be invalids or young children, it is considered that the structural elements such as floors, walls, partitions, and structural frame should in general satisfactorily resist the effect of the house fire for at least 30 minutes.

External Walls and Internal Partitions

267. In the normal house the risk of spread of fire is kept within reasonable bounds by the use of 9 in. or 11 in. brick walls and brick clinker block, or lath and

[1] This is not intended to apply to materials for skirtings, picture rails, and dadoes of limited height used in conjunction with brick, concrete blocks, etc.

plaster partitions. The 9 in. and 11 in. brick walls attain Grade A (6 hours) fire resistance and are more than is necessary. The fire resistance of 4½ in. brick and 4 in. clinker block partitions is about 2 hours, which is again more than necessary, whilst that of the lath and plaster partition is about ½ hour, but experience with it suggests that it is adequate for safety even though it may be ultimately completely destroyed.

268. The doors in partitions are the weak point, as they may be left open and permit the passage of smoke and flame; smoke alone may be sufficient to jeopardize escape even in the early stages of the fire. In any case, the normal panelled door resists fire for a much shorter period than the lath and plaster partition. Whilst there are indications that doors of better performance can be made at no greater cost than the present type, it is not considered reasonable to specify any standard. It is, however, clear that the conditions which would develop if the fire could spread through the whole length of a partition and the door, would be much more serious than those which would occur if the door only were vulnerable.

269. Data which are available, admittedly scanty, suggest that the initial 30 minutes of a house fire is equivalent to 15–30 minutes exposure in the standard test, much depending on the amount and type of furniture, combustibility of floors, etc. It seems desirable, therefore, that walls and partitions should be capable of resisting exposure to standard fire conditions for at least ½ hour, *i.e.* the period of exposure to fire required for attaining Grade E fire resistance. To attain this grade, however, several conditions must be satisfied (see Appendix VI), but it is considered that compliance with all the conditions of test is unnecessary in respect of house construction, as they were designed to take account of factors mainly of importance in large buildings. We suggest therefore that, for the purpose of testing external walls and partitions intended for use in house construction, a modified form of test for Grade E fire resistance should be adopted in which the test load is reduced to the design load, instead of one and a half times the design load, and the rise in temperature on the unexposed face should not be taken into account as a criterion of failure, as is the case at the present time in testing iron and steel fire resisting doors, glazing, etc.

270. Every external wall and certain partitions should at least comply with the above grade. In view of the fact that many partitions between rooms are of a "temporary" character, *e.g.* folding wooden doors between lounge and dining room, cupboard partitions between bedrooms, etc., it would be unreasonable to require all partitions to conform to this standard. We consider, however, that the grade should apply to all partitions bounding means of egress, and to all load-bearing partitions or parts thereof, excluding doors in each case. Available data indicate that this grade is attained by most stud partitions lined with incombustible material, but fibreboard and plywood linings would not, according to the same source, provide this standard. It is clear that the use of such combustible material will entail a reduction in the generally desirable standard of safety. Although combustible partitioning such as matchboarding and untreated fibreboarding on studding is in fact in use at the present time, experience with fires in other classes of buildings leads to the conclusion that unrestricted use of such construction would increase the risk of loss of life in small dwellings. This does not imply that combustible boards, adequately protected by treatment or associated with incombustible materials which afford the necessary resistance to fire, need necessarily be excluded, but emphasis is given to the conclusion arrived at from consideration of the problem from the standpoint of spread of flame that the manner in which such materials are proposed for use should always be carefully considered.

Floors

271. Turning now to the question of floors, we suggest that although there is occasional loss of life or injury owing to fire starting in or penetrating the floor,

there is no evidence to show that the normal timber joist floor with plain-edge boarding and wood lath and plaster ceiling has presented any serious hazard in its long period of use. It has therefore been adopted as the standard which should be attained by other types of floor and its endurance under test may be taken as the basis for establishing criteria for other types. Under standard fire test conditions the normal floor behaves broadly in the following manner. Plaster begins to fall after a short period of exposure, followed by ignition of the wood laths and, later, of the joists and underside of the boarding. Then within a few minutes flames appear above the surface of the floor through the joints between the boards, but, although this flaming increases in intensity, the floor structure remains stable and supports the uniformly distributed superimposed load. Within the period during which the plaster remains in position the temperature rise of the upper surface of the boards does not exceed 139° C., *i.e.* the limit in *B.S.* 476.

272. The appearance of the flames through the joints between the boards is governed by the behaviour of the plaster ceiling, for as soon as the plaster falls there is virtually no obstruction to the passage of flame. In the tests which have been made on various timber floors, some of which were pugged or had tongued and grooved boards, the plaster fell at times varying from 10–34 minutes from the start of the test, and in the test on the simple floor with plain-edged boards, flames appeared on the upper surface within a few minutes. From these figures it seems reasonable to assume 15 minutes as the time for which plaster ceilings on wood lath afford protection against flame penetration, but as the tests were not continued after flame penetration had occurred, it is not possible to say definitely when the floors would have collapsed, but it seems likely that it would not have occurred in less than ½ hour. We suggest that further tests should be made to examine this point, and as an interim measure assume that the resistance against collapse is at least ½ hour.

273. It is suggested therefore that all floor constructions should attain at least the standard determined by the following conditions, when subjected to the British Standard test:

1. The floor structure should be capable of supporting the designed superimposed loading for not less than 30 minutes without the deflection exceeding one-twentieth of the span.
2. No flaming should appear above the surface of the floor during the first 15 minutes of the test.
3. The average temperature rise of the upper surface of the floor should not exceed 139° C. during the first 15 minutes of the test (not measured over joints between surfacing).

274. We appreciate that this standard may exclude certain types of ceiling because they may allow flame penetration in a shorter time than lath and plaster. Ceilings which do not afford that protection should be regarded as sub-standard, but the increase in hazard due to their use may not justify their exclusion at a time when material is in short supply. At the same time it must be clearly appreciated that we regard them as sub-standard, and in any case there should be no reduction in the period of resistance against collapse. The use of tongued and grooved boarding is likely to improve conditions in this respect.

Structural Framework

275. In many alternative systems proposed for house construction in the post-war period the loads are carried by structural framework. It is clear that the frame must have adequate fire resistance, but in most cases the frame and cladding can be regarded as a unit and its fire resistance should comply with the proposed

standard for walls. Alternatively the members of a structural frame could be separately protected, but this method would probably be more costly as the cladding designed to satisfy other requirements, *e.g.* thermal insulation, resistance to damp penetration, may often afford the necessary protection against fire. Members of a frame which are independent of the wall system must, of course, be considered independently and should be protected to afford ½ hour fire resistance. It is not suggested, however, that this is necessary in the case of roof trusses for which unprotected steel may be used.

MEANS OF ESCAPE

276. In the one- and two-storey house special provision for means of escape is unnecessary, the means of access via passages and staircase being usually adequate to provide means of escape in case of fire, though windows in the upper storey should be of sufficient size to permit rescue in an emergency.

Construction of Staircase

277. The normal timber staircase is, like the timber floor, an accepted form of construction. Although it is combustible it retains its stability for some time even after it is ignited, and usually remains sufficiently strong to be used by firemen in an emergency. On the other hand, a staircase, *e.g.* of thin plywood, might ignite and burn far more rapidly. It is difficult to lay down the desirable criteria, because so far as is known no tests have been made. But it is suggested that no staircase used in a house should ignite more readily nor collapse under fire in a shorter period than the normal timber staircase. As indicated in Table 10, only materials conforming to Class 1 should be used on walls adjoining staircases.

DAMAGE HAZARD

278. In the above discussion of personal hazard, provisions have been suggested which would minimize the risk to the occupants of a house, but these provisions would not prevent the house being gutted if the fire were permitted to develop. This is the case with normal construction, but usually the occupants or neighbours attack the fire and summon the fire services. The efficiency of this fire fighting may be judged by the fact that the majority of house fires are confined to the room in which they originate. The more extensive use of inflammable materials would doubtless lead to a greater degree of fire damage, but the extent to which this can or should be offset by structural precautions additional to those necessary for personal safety must be related to the extra cost involved. It may prove cheaper and better policy to suffer considerable structural damage on a few occasions than to incur the cost of widespread extra precautions.

279. The question can be considered on the basis of the general grading, and a house could be erected in any of the types of construction, provided that, where the fire resistance requirements of any type fell below those required above for personal safety, the standard should be increased accordingly. Thus, as the dwelling house can be regarded as an occupancy of low fire load, a fire resistance of 1 hour at least would be necessary to ensure freedom from collapse. But as, in general, in those types having higher grades of fire resistance than that required on the grounds of personal safety the protection normally represents an additional charge on the cost of building, their adoption must be for the discretion of the building owner. The fact that the additional structural protection is an additional charge for which there is no advantage except when a fire occurs, does not justify setting up standards which, considered on the basis of thousands of houses, may well increase the cost by a very large sum, when in fact the protection is of value in relatively few instances.

SEPARATING WALLS

280. Whilst generally it is not considered necessary to set up standards of structural protection over and above those required to ensure safety of occupants, there are certain parts of the structure in which some additional structural protection is desirable. So far as one-family dwellings are concerned, the separating wall is the only item.

281. Hitherto, houses built in pairs or in terraces have been separated, in accordance with building regulations, by walls of brickwork having a minimum thickness of 8½ in. Such walls, while fulfilling several functions, have proved particularly suitable in preventing spread of fire internally between houses, and, in addition, owners or occupiers have enjoyed immunity from damage to their property even when an adjoining house has been gutted by fire. It is realized, however, that as far as actual spread of fire is concerned, the high fire resistance (6 hours) of the 9 in. brick wall is in excess of what is needed for that purpose. As generally the dwelling house falls within the low fire load class of occupancy, a wall having a fire resistance of 1 hour should suffice, even to resist a complete burn-out. In certain instances, however, if the construction is mainly combustible, the fire load may fall in the moderate class and a fire resistance of not less than 2 hours Grade C should be necessary for the separating walls.

282. It must be pointed out, however, that many types of wall construction which conform to these reduced standards are more liable to damage than the 9 in. brick wall when fire occurs, and an adjoining owner may be inconvenienced as a result. Questions arising from the rights of adjoining owners may therefore need consideration. Again, walls of relatively flimsy construction, such as light steel framing with thin lining materials, although giving 1 hour fire resistance, will not be so durable under conditions of normal usage as the brick wall. The disadvantages of the lighter walls must be balanced against the fact that few fires in houses develop beyond the room in which they originate, or do more than superficial damage to the structure around that room, and that many types of wall of less standard of fire resistance than the 9 in. brick wall may function much better in other respects, *e.g.* minimizing noise penetration, and may be more economical and more easily built.

283. Therefore in recommending that separating walls should generally have a fire resistance of at least 1 hour (Grade D), we are aware that there are other aspects of the question, not directly connected with spread of fire, which should receive consideration and which may make necessary the use of certain types and thicknesses of materials automatically giving a higher standard of fire resistance.

284. We consider that only incombustible materials should be used, or materials which may be deemed incombustible for use in building, *e.g.* wood wool slabs, and would emphasize that, especially in the case of light framed cavity separating walls, the junction with an external wall and roof should be effectively sealed to prevent the leakage of smoke and flame, and to this end it may be necessary where walls or roof covering are of inflammable material to continue the separating wall through the external wall or the roof.

Steelwork in Separating Walls

285. We understand that in many alternative systems of house construction proposed for post-war use the separating wall may be of framed construction. Whilst from the standpoint of fire resistance the frame and cladding may be considered as a unit which must comply as a whole with the recommended grade, the fact that a continuous frame may form part of each house introduces a risk

of damage to adjoining houses when fire occurs in one, because of stresses set up by thermal expansion and ultimately by possible collapse. We consider, however, that the risk is reasonably minimized by the fire resistance requirements proposed, but would draw attention to the advantage gained in this respect by forming the wall of two independent frames each of which is part of the main framework of one house. The separating wall then consists virtually of two external walls.

EXPOSURE HAZARD

286. Whilst safeguards against the hazard of fire spreading into a house through its external walls or roof may again be provided by requirements in respect of ease of ignition and fire resistance, we have seen that the risk may also be reduced by spacing the building from adjacent fire risks and by fire fighting, and in formulating requirements a proper balance between the four methods should be obtained.

The external wall of brick and fire retardant roof covering on houses of normal construction reduce the risk of conflagration to negligible proportions in present-day housing development of 12–16 houses per acre. The only appreciable risk of spread arises from windows, but experience indicates that no special structural precautions, such as the provision of fire resisting glazing, are necessary.

DWELLINGS WITH COMBUSTIBLE EXTERNAL WALLS OR NON-FIRE-RETARDANT ROOF COVERINGS

287. Our proposals in Section I relating to the spacing of buildings having combustible external walls, or non-fire-retardant roof coverings, apply to dwelling houses, and they are reproduced here for ease of reference.

1. *Houses with Walls having External Combustible Coverings.* Single house or pair of houses not exceeding 36,000 cu. ft. in total capacity (no house in pair to exceed 18,000 cu. ft.). Separation to be 20 ft. if capacity of the house does not exceed 18,000 cu. ft.; to be 40 ft. if capacity is greater; or half these distances from the boundary of the site.
2. *Houses with Non-Fire-Retardant Roof Coverings.* Single house or pair of houses not exceeding 36,000 cu. ft. in total capacity. Separation to be four times the height or half this distance from the boundary of the site.

We would emphasize again the need for special consideration of proposals for the use on any extensive scale of external walls or roofs of inflammable materials. Careful consideration should be given to the proposed layout from the standpoint of conflagration risk. Wood shingles should be permitted only on isolated buildings.

DWELLINGS WITH INCOMBUSTIBLE EXTERNAL CLADDING

288. In the general section on exposure hazard we have proposed (paragraph 183) certain spacings between walls which are of less than 2 hours fire resistance, with a relaxation if the buildings are less than 20,000 cu. ft. in cubic capacity. Although ordinary small houses would fall below this limit, they present a special aspect of this problem on account of their numbers, and we feel that special separation is desirable.

289. Our recommendations are set out in Table 11, where we give the distances which should separate walls having the indicated fire resistance. These distances are partly derived from corresponding requirements in the Model Bye-laws. It should be noted that the fire resistance is determined by exposure of the outer face. The number of houses in any block should be limited to the number given in Column 4 of the Table.

TABLE 11. PROXIMITY OF EXTERNAL WALLS OF HOUSES WITH INCOMBUSTIBLE MATERIAL EXTERNALLY

CONSTRUCTION (1)	FIRE RESISTANCE OF FRAME AND WALL (Exposure on *Outer* Face) (2)	MINIMUM DISTANCE BETWEEN WALLS* of SAME CONSTRUCTION AND FIRE RESISTANCE (3)	NUMBER OF HOUSES IN BLOCK (4)
Load-bearing walls or walls with frame of incombustible material. (Minimum fire resistance against internal exposure to fire, ½ hour.)	Not less than ½ hr.	No Restriction	No Restriction
	Less than ½ hr.†	10 ft.	6
Frame of combustible material. (Minimum fire resistance against internal exposure to fire, ½ hour.)	Not less than ½ hr.	10 ft.	4
	Less than ½ hr.	16 ft.	4

* If the distance is measured from the boundary of the site, half the distances in Col. 3 should be taken.

† If the fire resistance of an external wall against internal exposure is at least 1 hour, no restriction need be imposed.

OTHER FACTORS

290. Normal house construction generally contributes to fire safety. With other types of construction there will be numerous features which will need consideration or they will result in an increased fire risk. Some of the more important are considered below:

HEATING AND LIGHTING INSTALLATIONS, ETC.

291. With the possible more extensive use of lighter forms of construction, some of which may be of combustible materials, precautions should be taken to ensure that departure from traditional forms of construction does not introduce new risks arising from heating and lighting installations, etc.

CHIMNEYS AND FLUES

292. The provisions in the Model Bye-laws for chimneys and flues relate essentially to brick or concrete chimneys. We shall consider this aspect generally in Part IV, for we understand that, with the development of new systems of construction, there is a tendency to depart from the traditional chimney construction.

HOLLOW SPACES IN WALL, PARTITION, AND FLOOR CONSTRUCTION

293. Hollow spaces between the two leaves of cavity walls form a ready means of spread of fire. There is virtually no risk in the normal house with cavity walls of bricks or blocks, but the problem occurs in framed walls with thin linings, especially if these are of combustible materials. In such cases fire may spread throughout the cavity from room to room and between storeys. Much attention has been devoted to this problem in America, and our knowledge is derived from their experience. To minimize this risk the cavity should be fire-stopped, *i.e.* it should be blocked with incombustible material so as to break the continuous

cavity; timber, if at least 2 inches thick, may also be used. The fire-stop should be imperforate and of the full thickness of the cavity. Openings for the passage of pipes and conduits should be of the minimum necessary size, and should preferably be provided with a metal sleeve, and where necessary the hole should be made good with incombustible material.

294. Generally fire-stopping should be inserted horizontally at ceiling level to minimize spread of fire between storeys and between the upper storey and the roof space, and vertically at wall junctions so as to minimize spread between rooms.

SINGLE-STOREY HOUSES (BUNGALOWS)

295. In this class of dwelling the risk to the occupants is largely reduced because there is no upper floor. Accordingly some of the standards proposed in earlier sections can be relaxed, as active occupants may more easily make their escape from windows in case of emergency. The provision of "french doors" would be an advantage in this respect. There would appear to be no need to insist on any specific grade of fire resistance if the walls are wholly of incombustible material, except, of course, in the separating walls. Fire fighting may need special consideration by the appropriate authorities.

296. The separation of bungalows having external walls of less fire resistance than the minimum proposed earlier for external walls (paragraph 269) may need to be greater than the minimum given in Table 11, but as the desired spacing may not be possible for economic reasons, this factor should be taken into account in considering fire fighting requirements.

TWO-STOREY HOUSES FOR TWO FAMILIES

297. This paragraph refers to blocks of 2-storey houses where each house is intended for occupation by two families, one in the lower storey and one in the upper storey, each family having its own separate access to the exterior at ground level. In the past normal house construction has been followed, but an additional safeguard to the occupants of the upper storey has been provided by separating their access staircase from the lower rooms. There is some justification for recommending that the separation should at all points afford not less than Grade E (½ hour) fire resistance. The normal timber floor, however, has been commonly used without, so far as we are aware, creating serious hazards. This suggests that the standard proposed for one-family houses would again be adequate, but it is considered that the construction which forms or supports the separation between the access staircase and landing and the lower storey should at all points afford not less than Grade E (½ hour) fire resistance, as modified in paragraph 269.

EXTENT OF LOSS

298. It must be appreciated that the risk of complete loss of contents and structure is greater in light and combustible types of construction than in houses in which specified grades of fire resistance are required, and, of course, in the normal house. It is very desirable, therefore, that the occupants should be made aware of the risk and of the need for continuous care.

SUMMARY OF RECOMMENDATIONS FOR ONE- AND TWO-STOREY HOUSES

TWO-STOREY HOUSES FOR ONE FAMILY

EXPOSED INNER SURFACES OF WALLS AND CEILINGS

299. The exposed surfaces of walls and ceilings should conform with the recommendations as set out in Table 10 and paragraph 265.

EXTERNAL WALLS

Fire Resistance

300. All external walls should have an adequate grade of fire resistance, sufficient at least to ensure that there is no risk of failure before the occupants have escaped. For this purpose we recommend that the fire resistance should be not less than Grade E (½ hour), *the test being modified by reduction of the test load from one* and a half times the design load to the design load only, and by the omission of the temperature rise on the unexposed face as a criterion of failure. Where full structural resistance against collapse is desired the fire resistance should be not less than 1 hour Grade D.

Location

301. External walls of houses should be located in relation to external walls of adjacent houses, other than those forming part of the same block, so as to ensure reasonable security against spread of fire from house to house. For this purpose walls should be separated by distances depending on the materials of construction and fire resistance given in paragraph 287 and in Table 11.

SEPARATING WALLS BETWEEN HOUSES

302. All separating walls between houses forming part of a block should ensure complete separation between the houses, be constructed of incombustible material, and have a fire resistance of not less than 1 hour Grade D.

INTERNAL WALLS AND PARTITIONS

303. All internal walls and partitions, excluding partitions formed by folding doors, cupboards and the like, should have a fire resistance sufficient at least to ensure that there is no risk of their failure before the occupants have escaped. For this purpose we recommend that they should attain Grade E fire resistance, modified as indicated for external walls.

STRUCTURAL FRAMEWORK

304. Where a structural framework forms part of a wall or partition or floor, the system as a whole should conform with the requirements for fire resistance for the wall or floor.

Members of a structural framework independent of any wall or floor should have a fire resistance of not less than ½ hour under their design load.

FLOORS

305. Floors should comply with the following conditions when subjected to the British Standard heating.

1. The floor structure should be capable of supporting the designed superimposed loading for not less than 30 minutes without deflection exceeding one-twentieth of the span.

2. No flaming should appear above the surface of the floor during the first 15 minutes of the test.
3. The average temperature rise of the upper surface of the floor should not exceed 139° C. during the first 15 minutes of the test (not measured over joints between surfacing).

HOLLOW SPACES IN WALL CONSTRUCTION

306. Hollow spaces in wall and partition construction should be suitably fire-stopped if they are lined with or contain combustible material. Fire-stopping should be inserted horizontally at ceiling level so as to minimize spread of fire between storeys, and vertically at wall junctions to prevent spread of fire between rooms. Fire-stops should be of incombustible material, but wood if at least 2 in. in nominal section may be used; they should be imperforate and of the full width of the cavity. Holes made for the passage of pipes and conduits should be of the minimum necessary size, preferably fitted with metal thimbles of the appropriate size; where necessary the hole should be made good with incombustible material.

STAIRCASES

307. Staircases should not ignite more readily nor collapse more easily under the effect of fire than the normal timber staircase.

SINGLE-STOREY HOUSES (BUNGALOWS)

308. Except for separating walls, the proposals in respect of fire resistance for two-storey houses may be relaxed in the case of single-storey houses, of which the external walls are constructed wholly of incombustible materials.

TWO-STOREY HOUSES FOR TWO FAMILIES

309. It is recommended that the standards proposed for single family houses should apply with the additional requirement that the walls, partitions, or any other construction separating the staircase and passages forming means of egress from the upper floor from the storey below should be not less than Grade E (½ hour) fire resistance modified as above.

C. Roland Woods, *Chairman*
E. L. Bird
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F. W. Jackson
R. T. Kennedy
G. D. MacNiven
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E. A. Oliver
A. S. Rogers
W. L. Scott
A. N. C. Shelley
Digby L. Solomon[1]
Guy Symonds
Sydney Tatchell
W. E. Thorowgood[1]
W. H. Tuckey
R. C. Bevan, *Secretary*

[1] Subject to a reservation (see below).

RESERVATIONS

Mr. Digby Solomon

1. Although the Report specifically states that the formulation of rules and regulations is a matter for separate consideration, I am of the opinion that where questions of safety of life, or damage and destruction to other people's property

by spread of fire, are involved, any recommendations made to attain this end should be of a compulsory nature and not merely the basis for a "permissive" code of good practice, to be adopted or not at the whim of a building owner or his professional adviser. I therefore consider that the value of the Report would have been greatly enhanced had it stated specifically which of its recommendations should be the subject of legislation.

2. Whilst in the main endorsing the Committee's findings from a theoretical or "scientific" point of view, it is my opinion that some of the recommendations, particularly those relating to "change of occupancy" and to "protection against exposure," will, if translated into legislative action, raise great difficulties in the design and use of buildings, and may in some instances unnecessarily increase the cost of building. Some of the recommendations do not appear to take into account the conditions which apply in normal building construction.

3. If the work of the Committee was intended to have the very full and comprehensive scope indicated in the Report, I consider it unfortunate that it is described as a report on the "Fire Grading of Buildings," as, to the lay mind, I do not think that this term conveys the idea that it includes such subjects, for example, as "Means of Escape from Fire," which it appears is intended to be taken in Part III.

If the Committee's wide interpretation of the words "Fire Grading of Buildings" is correct, then I consider that, as the ultimate aim of the work should obviously be to limit the loss from fire, the Report loses a great deal of its value because it was decided to limit the inquiry to questions arising out of the development and spread of fires which have already started, *i.e. fire protection*, and not to deal with questions relating to the *prevention* of outbreaks of fires. In my opinion the two subjects of fire protection and fire prevention are so intimately bound up with each other that it is virtually impossible to separate one from the other, and recommendations made to reduce the number of outbreaks of fire should be at least of equal value to those made to prevent the spread of fire, and might even conceivably cut out many of the recommendations made in respect of the latter. For example, many fires start because old buildings of timber floor and roof construction are, without proper advice, subsequently equipped with installations—such as a central heating system or a boiler plant—for which they are not fitted. For this reason I hope that this Report will shortly be implemented by one based on an inquiry into the reasons why fires start.

DIGBY L. SOLOMON

Mr. F. H. Durant and Mr. W. E. Thorowgood

We are not in agreement with the insertion in the Report of paragraph 131 for the following reasons:

The suggested floor area and cubical capacity has no reasonable relation to the carefully considered limitations of floor area and cubical capacity contained in the Tables.

If accepted, it would be difficult for the Committee, or a responsible authority in administration, to justify compliance with the limitations of floor area and cubical capacity in any user coming within the moderate fire load (normal) grading, and would, in our opinion, render abortive much of the Committee's work. The risk of outbreak of a fire in a department store building is greater than in the majority of the occupancies of this fire load.

A department store often contains materials of inflammable character in addition to quantities of highly combustible flimsy material.

Although the suggestion contained in paragraph 131 is for one well, acceptance of the principle would render it unreasonable to object to two or more wells, unenclosed lifts and staircases, escalators, etc., within the same compartment or division.

The result would be that a building could be erected of several million cubic feet in one fire risk. In this connection, we would invite attention to paragraphs 120 to 124 of the Report of the Royal Commission on Fire Brigades and Fire Prevention dated 1923.

Although the Paris building referred to in the Report of the Commission was not provided with sprinklers except in the sub-basement, it should not be overlooked that sprinklers are not infallible. Moreover, a fire might spread with such rapidity as to get beyond the control of a sprinkler installation. This latter possibility is present particularly in a building where quantities of flimsy and highly combustible articles are spread and hung about the whole compartment and where a well operating as a flue would encourage spread of fire.

Moreover, an open well, in addition to encouraging upward spread of fire from storey to storey, also provides unobstructed means for downward spread of fire by means of blazing brands or debris falling from the upper galleries or storeys to the lower floors.

Although the question of risk to life will be dealt with separately, in considering the size of compartments and the provision of galleries around an open well, it must not be overlooked that, at the sight of flame or smoke, the fear of burning or suffocation may completely change the otherwise logical behaviour of human beings. In the rush some persons may try to make their escape regardless of others. Even when within a properly enclosed staircase, persons at a high level, such as the upper galleries of the type of building under consideration, to which the majority of them are strangers, are prone to imagine that reckless flight down the stairs into the street is essential for their safety. The risk involved to slow moving persons, such as women with children, is considerable, and a calamity might easily result upon the occurrence of a comparatively small fire.

The argument contained in paragraph 131 is unsound. We do not agree that by allowing concessions (out of all reasonable relationship to the Committee's carefully considered limitation of floor area and cubical capacity contained in the Tables) some of the unsatisfactory buildings at present existing in the country might be replaced. It would unquestionably result in the erection of buildings out of all reasonable conformity with the Tables and with no assurance that any of the unsatisfactory buildings referred to would be replaced.

The accepted principle that responsible authorities should allow reasonable departures from the Tables in appropriate cases would afford these authorities an adequate opportunity for allowing concessions in special circumstances with due regard to the risks which must be present.

Should, however, the paragraph 131 be included as a guide for responsible authorities, it would unquestionably result in the conclusion that all buildings in the same classification of fire load (subject to site, etc.) are entitled by right to the maximum floor area and cubical capacity contemplated by the paragraph, and it might be argued that proportionate increases would be applicable to all other classes of fire load.

If adopted, as a typical example, the paragraph would, in our opinion, nullify the carefully considered decisions of the Committee, as set out in the Tables relative to floor area and cubical capacity.

F. H. Durant

W. E. Thorowgood

APPENDIX I. ABNORMAL MATERIALS

The following is a list of materials the presence of which in appreciable quantities in a building would usually justify grading of the occupancy as abnormal. The list is by no means exhaustive.

Acetone, 4[1]
Acetone oils, 4
Acetylene, 2
Acids, Acetic, 5; Chromic, 5, 6, 7A; Hydrochloric, 5; Nitric, 5, 7A; Oxalic, 5, 6; Picric, 1; Sulphuric, 5
Alcohols, 4
Ammonia, 2 or 6
Amyl acetate, 4
Animal black, 9
Anthracene, 7

Bags and sacks which have contained nitrates, sugar, oily, greasy, or treacly materials, 7, 9
Benzene (benzol, benzole), 4
Benzine, 4
Bitumen, 7, 8
Blacks, 9
Bronze powder, 7C
Brunswick black, 9
Butyl acetate, 4
Butyl aldehyde, 4
Butyl cellosolve, 4
Butyl lactate, 4

Calcium carbide, 3A
Carbon bisulphide, 4
Carbon black, 9
Carbonyl chloride (phosgene), 2, 6
Caustic potash, 5
Caustic soda, 5
Cellosolve, 4
Cellosolve acetate, 4
Celluloid articles and preparations, 4
Charcoal black, 9
Chlorates, 7A
Chromates and bichromates, 7A
Collodion, 4
Copra, 7B
Creosote, 8
Cyanamide, 3

Ethyl acetate, 4
Ethyl butyrate, 4
Ethyl chloride, 2
Ethyl ether, 4
Ethyl lactate, 4

Fats, 7 and 8
Felt, asphalted, asphalt—saturated, bituminous, or tarred, 7
Fibres and grasses, vegetable, 7B and 7C
Films, celluloid, 7C
Firelighters, 7C
Fireworks, 1
Flash powders, 1
Flock, 9
Fodder, dried, 7B
French polish, 4

Gas black, 9
Greases, 7C, 8

Inks, printing, 4
Insecticides, 9

Matches, 7C
Metallic powders, 7C, 9
Methyl acetate, 4
Methylated spirit, 4
Methyl cellosolve, 4
Methyl chloride, 2
Methyl ethyl ketone (M.E.K.), 4

Naphtha, 4
Naphthalene, 7C
Nitrates and nitrites, 7A

Oils, 4, 8

Paints and varnishes and lacquers, 4
Paper: asphalted, oiled, or tarred, 7C
Paraffin wax, 7C, 8
Perchlorates, 7A
Permanganates, 7A
Peroxides, 7A
Persulphates, 7A
Petrol, 4
Petroleum jelly, 7A, 8
Phenol (carbolic acid), 5, 6
Phosphorus, 3B and 7C
Pitch, 7C, 8
Polishing liquids, creams, and pastes, 4

Rags, 7B
Resins, 7C
Rope, tarred, 7C
Rosin, 7C
Rubber, 7C
Rubber solution, 4

Sawdust, 9
Shavings, wood or paper, 9
Spanish black, 9
Stains, 4
Sulphides of phosphorus, 3B; sodium, 3B; potassium, 3B
Sulphur, 7C
Sulphur chlorides, 5

Tars, 4
Tarred cloth, felt, paper, string or twine, 7C
Toluene (toluol), 4
Turpentine, 4
Turpentine substitute—white spirit, 4

Vegetable down, 9

Waste of all kinds, 7B, 9
Wood flour, 9
Wool grease, 7C, 8

[1] The number after each material refers to the categories in paragraph 35.

APPENDIX II. ABNORMAL OCCUPANCIES

The following is a list of some industries which would usually be regarded as falling into the abnormal class. The list is by no means exhaustive.

Aircraft Manufacturing
Artificial Flower Manufacturers
Artificial Leather Manufacturers
Artificial Silk Manufacturers

Basket Makers
Bedding Manufacturers
Bookbinders
Boot and Shoe Manufacturers
Brush Makers

Cabinet Makers
Calenderers
Candle Manufacturers
Cardboard Box Manufacturers
Cellulose Spraying
Cloth Lappers
Clothing Manufacturers
Confectioners, Manufacturing
Cotton Mills
Curriers

Distillers
Druggists, Wholesale or Manufacturing
Dry Cleaners
Drysalters

Envelope Makers
Esparto Dealers

Film Dealers
Firework Dealers
Flannel Manufacturers
Flax, Hemp, Jute Mills
Floor Polish Manufacturers
Flour and Grist Millers
French Polishers
Furniture Manufacturers
Furriers

Gas Singers

Hat Makers
Hay and Straw Dealers

Japanners

Lace Manufacturers
Linoleum Manufacturers
Lithographers

Match Manufacturers
Methylated Spirit Manufacturers

Oil and Colour Dealers
Oil Refiners

Packing Case Manufacturers
Paint and Varnish Manufacturers and Dealers
Paper Bag Makers
Paper Manufacturers
Printers

Rag and Waste Dealers
Rice Millers
Rope Makers
Rubber Goods Manufacturers and Dealers

Saw Millers
Seed Crushers
Ship Chandlers
Stationers, Manufacturing
Starch Dealers
Straw Goods Manufacturers
Sugar Refiners

Tanners
Tar Distillers
Tarpaulin Makers

Upholstery Manufacturers

Wallpaper Manufacturers and Dealers
Waterproof Clothing Manufacturers
Woollen Manufacturers
Woollen Mills
Woodworking

APPENDIX III. CALORIFIC VALUES OF MATERIALS

The calorific values of the materials in the following Tables have been collected from various sources, chief of which are:

1. International Critical Tables.
2. Smithsonian Tables.
3. Landolt Börnstein Physikalisch Chemische Tabellen.
4. Bureau of Standards Journal of Research.
5. Handbook of Chemistry and Physics, Twentieth Edition: C. Hodgeman.

The values are given to the nearest 100 B.Th.U's.

L=Liquid.
G=Gas.
S=Solid.

MATERIAL		B.TH.U'S./LB.	MATERIAL		B.TH.U'S/LB.
Acetaldehyde	L	11,400	Acids :		
Acetone	L	13,500	Acetic	L	6,300
Acetylene	G	21,600	Benzoic	S	11,700
Acetanilide	S	13,500	Carbolic	L	14,000

MATERIAL		B.TH.U'S./LB.
Citric	S	4,500
Formic	L	2,500
Lactic	S	6,300
Oleic	L	16,900
Oxalic	S	1,200
Palmitic	S	17,000
Picric	S	4,900
Stearic	S	17,100
Tartaric	S	3,300
Alcohols :		
Allyl	L	16,200
Amyl	L	13,700
Butyl	L	15,500
Cetyl	S	18,600
Denatured	L	11,700
Ethyl	L	12,900
Methyl (Wood)	L	9,600
Propyl	L	14,500
Aldol	L	11,200
Allylene	G	21,200
Amyl acetate	L	14,400
Amylene	L	20,600
Aniline	L	15,700
Anthracene	S	17,200
Asphaltum	S	17,400
Bagasse (53 % moisture)	S	4,000
Benzene (Benzol)	L	18,000
Benzoin	S	9,100
Bitumen	S	15,200
Butane	L	21,400
Butylene	G	20,900
Caffeine	S	8,600
Camphene	S	19,000
Camphor	S	16,200
Carbon	S	14,600
Carbon disulphide	L	10,100
Casein	S	10,500
Cellulose	S	7,500
Cellulose acetate	S	8,100
Charcoal	S	12,900
Chloroform	L	1,300
Coal :		
Anthracite	S	13,300
Bituminous	S	14,000
Sub-bituminous	S	10,000
Coke (av.)	S	12,500
Cotton (combed and air dried)	S	7,200
Cyanogen	G	9,000
Decane	L	20,400
Dextrin	S	7,800
Diethyl ether (Ether)	L	16,500
Dimethyl ether (methyl)	G	13,600
Dynamite	S	2,300
Ethane	G	22,300
Ethyl acetate	L	10,900
Ethyl bromide	L	5,700
Ethyl iodide	L	4,200
Ethylene	G	21,700
Flax	S	6,500
Foodstuffs :		
Barley		6,400
Bread		4,500
Corn meal		6,400
Flour		6,400

MATERIAL		B.TH.U'S./LB.
Hominy		6,400
Macaroni		6,400
Oatmeal		7,200
Rice		6,300
Soya bean flour		7,300
Wheat (whole)		6,500
Wheat (bran)		5,000
Butter		13,400
Cheese (Cheddar)		8,200
Prunes (dried)		6,600
Raisins		6,200
Bacon		11,300
Beef (av.)		4,000
Sardines in oil		5,700
Gelatin		6,600
Margarine		13,400
Nuts :		
Almonds		11,600
Brazils		12,500
Chestnuts		4,400
Coconut (dry)		12,000
Peanuts		10,000
Walnuts		12,700
Miscellaneous :		
Chocolate (unsweetened)		11,000
Chocolate (sweetened)		9,100
Cocoa		8,900
Honey		5,900
Syrup		5,000
Marmalade		6,000
Molasses		5,200
Olive oil		16,700
Sugar (sucrose)		7,000
Formaldehyde	G	8,000
Furs and Skins (av.)	S	8,500
Gas : B.Th.U's./cu. ft.		
Natural 710–2,250		
Oil 510– 800		
Coal 450– 670		
Producer 100– 180		
Water 300– 670		
Glucose	S	6,700
Glycerine	S	7,700
Glycerol	L	7,700
Graphite (plumbago)	S	14,200
Guncotton	S	1,900
Gunpowder	S	13,500
Hair (cattle)	S	9,500
Hexane	L	20,400
Hydrogen	G	61,000
Indigo	S	12,500
Inulin	S	7,500
Leather (av.)	S	8,000
Lignite (av.)	S	6,500
Magnesium	S	10,900
Methane	{ L G }	24,000
Naphthalene	S	17,300
Nicotine	L	15,800
Nitro-benzene	L	10,900
Nitro-glycerine	L	3,400
Octane	S	20,600

MATERIAL		B.TH.U'S./LB.	MATERIAL		B.TH.U'S./LB.
Oils and Waxes :			Rubber	S	17,000
Vegetable, nut, and animal oils	L	17,100	Silk (raw)	S	9,200
Castor	L	16,000	Starch	S	7,500
Coal Tar	L	18,400	Stearin	S	16,900
Fuel	L	18,900	Straw (av.)	S	6,000
Gas	L	19,500	Sulphur	S	4,500
Mineral lubricants	L	17,100			
Paraffin	L	18,000–20,000	Tallows	S	17,100
Sperm	L	18,000	Tanbark	S	9,500
Tallow	S	17,100	Tar (bituminous)	S	16,000
Ozokerite (wax)	S	19,700	Toluene	L	18,300
Paper (av.)		7,000	Waxes	S	17,000
Paraffin	S	18,600	Woods :		
Peat	S	10,000			
Pentane	G	20,900			
Petroleum products :			Average for soft and hard woods (approx. 12% moisture content)	S	8,000
Crude and fuel oil (av.)		19,000	Wool (raw)	S	9,800
Petrol (av.)		20,000	Wool (scoured)		8,900
Phenol (carbolic acid)	S	14,100			
Pitch	S	15,000	Xylene	L	18,400

APPENDIX IV. SEVERITY OF BUILDING FIRES

The method referred to in paragraph 52 of the Report for estimating the severity of building fires is based on the fact that brickwork mortar and concretes made with siliceous and many natural stone aggregates show certain colour and other changes which develop at fairly well defined temperatures. The colour changes appear to be due to the presence in the aggregate, or in clay associated with the aggregate, of small quantities of hydrated ferric oxides which on heating become dehydrated or react with the lime content of the cement to produce the observed changes. Other changes, such as the complete loss in strength, are due to disintegration of siliceous material, *e.g.* α—β quartz change. The main data relating to these changes which are relevant to the present discussion are given in Table 1; the temperatures indicated are mean values, as the changes occur over a small range of temperature.

TABLE 1. COLOUR CHANGES IN CONCRETES AND MORTARS

DESCRIPTION OF CHANGE	TEMPERATURE AT WHICH CHANGE OCCURS
1. From normal unheated appearance to pink, red, or reddish brown	300° C.
2. Disappearance of pink or red, reverting almost to normal grey. Particles of coarse aggregate may remain red. Marked loss of strength	650° C.
3. Further colour change to buff	1000° C.
4. (i) Sintering of concrete and mortar (ii) Fusion of bricks	1250° C.

These mean temperatures have been determined on small samples of natural stones, small brick panels, concrete slabs, and also in full-scale tests on walls and columns carried out in furnaces at the Fire Testing Station at Elstree. The results of one of the latter tests on a solid brick wall subjected to exposure for 2 hours according to the standard time-temperature curve are given in Fig. 4. The full curve represents the maximum temperatures reached in the wall as measured by embedded thermocouples. After the test the wall was cut open and the depths from the heated surface to which the various colour changes had penetrated were observed. They were as follows:

Buff coloration	¼ in.
Grey coloration	1 in.
Pink coloration	3 in.

It follows therefore that at ¼ in. from the surface the temperature had just reached 1000° C., the temperature at which the buff change occurs; at 1 in. from the surface the temperature had just reached 650° C., etc. The dotted curve in Fig. 4 shows the points plotted to give the temperature gradient, giving reasonable agreement with the measured temperatures.

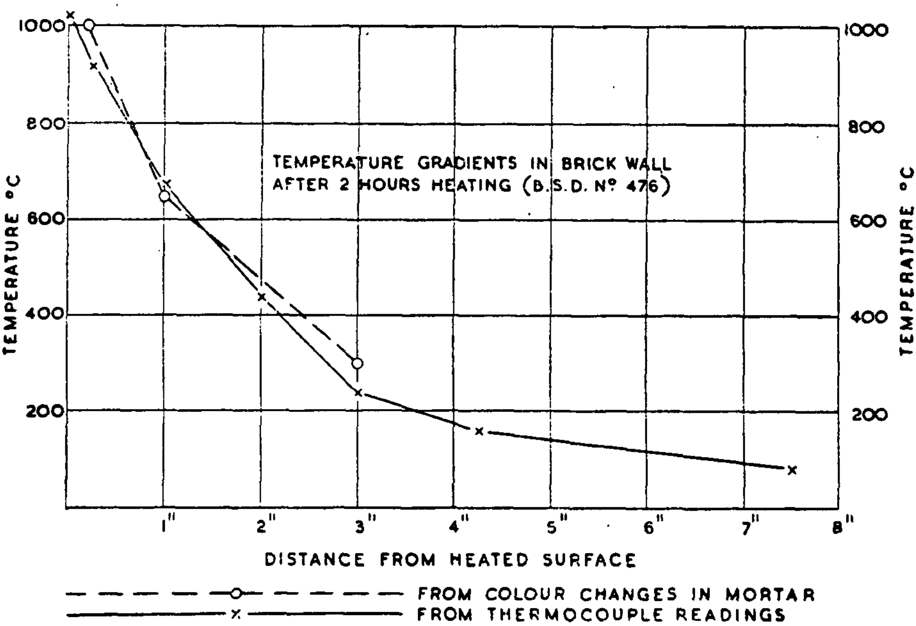
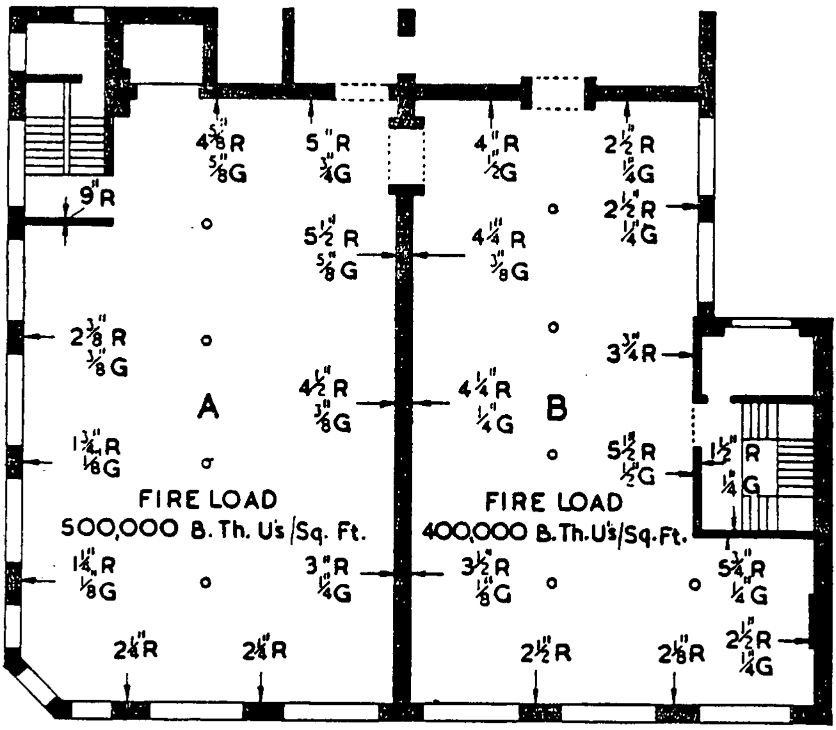


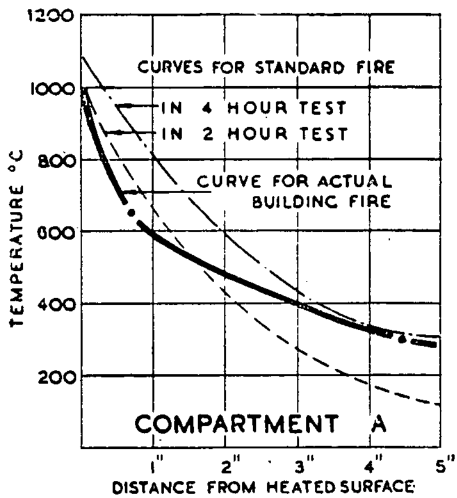
Fig. 4. COMPARISON OF TEMPERATURE GRADIENT IN WALL AS MEASURED BY THERMOCOUPLES AND BY COLOUR CHANGES

APPLICATION TO BUILDINGS

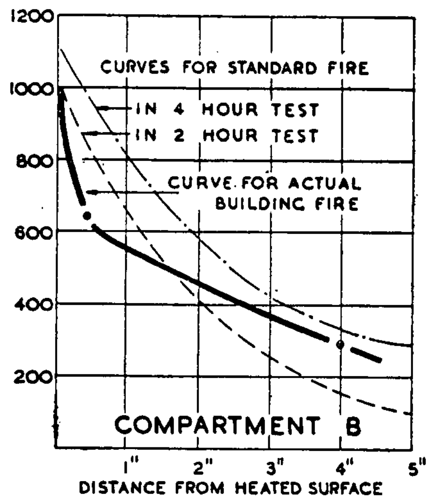
In applying the method to actual building fires the first procedure is to cut into the walls or columns of the building to determine the depths to which the change has penetrated in the mortar or concrete. A typical record of results obtained in two compartments of a storage building separated by 22½ in. brick division wall is given in Fig. 5 (a). The record indicates that the heating in the parts adjoining this wall was, as might be expected, more severe than the heating of the walls near the windows, a feature attributable to loss of heat through the windows. The mean of these measurements on the division walls were used to plot the temperature gradient in Fig. 5 (b). The surface temperature has been assumed to be the maximum temperature noted in the fire. This is probably higher than the actual surface temperature. The figure also shows the temperature gradients attained in a brick wall after exposure to 2 hours and 4 hours heating according to the standard time-temperature curve. It will be noted that the 2 hours test curve crosses the building fire curve, whilst the 4 hours test curve lies



(a) DEPTHS OF COLORATIONS
G=Grey Coloration R=Red Coloration

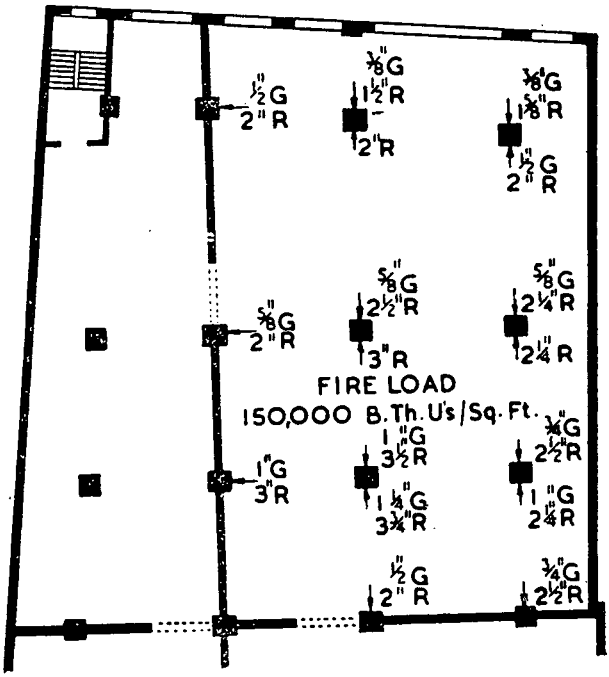


(b) AVERAGE TEMPERATURE GRADIENTS IN WALLS



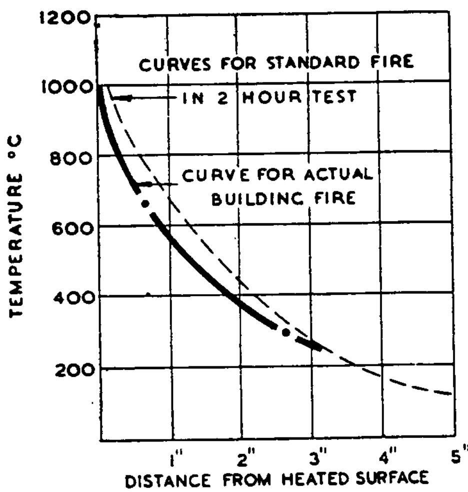
(c) AVERAGE TEMPERATURE GRADIENTS IN WALLS

Fig. 5. TEMPERATURE GRADIENTS INSIDE A WALL SUBJECTED TO FIRE
(See Appendix IV)



(a) DEPTHS OF COLORATIONS

G=Grey Coloration R=Red Coloration



(b) AVERAGE TEMPERATURE GRADIENT IN COLUMNS

Fig. 6. TEMPERATURES INSIDE COLUMNS SUBJECTED TO FIRE (See Appendix IV)

wholly above it. For present purposes it has been assumed that the severity of the building fire is equivalent to that period of exposure to the standard heating which causes the temperatures at all points in the thickness of the wall or column to be greater than those caused by the building fire. The equivalent severity of the fire in compartment A is therefore 4 hours. This basis of comparison gives results which are probably on the safe side, and more detailed analysis of the matter is necessary, taking into account criteria of failure, etc., before a more exact comparison can be made.

Corresponding curves for compartment B are shown in Fig. 5 (c), whilst in Fig. 6 the results obtained in another storage building are shown. In this case the results are based on measurements of the depth to which the changes occurred in the reinforced concrete columns. The temperature gradient for the building columns and a 2 hours test on a reinforced concrete column are shown in Fig. 6 (b), from which it will be noted, on the above assumption, that the fire was equivalent to about 2 hours exposure.

RELATION BETWEEN SEVERITY AND FIRE LOAD

From a knowledge of the fire load of any building or compartment it is now possible to determine the relation between the severity of the fire and the fire load. Estimates of the fire load in the examples quoted above gave values in the first case of 500,000 B.Th.U's./sq. ft. consisting chiefly of clothing for compartment A, and 400,000 B.Th.U's. for compartment B, and 150,000 B.Th.U's./sq. ft. in the latter example. The method has been applied to various buildings ranging from office occupancies, having relatively low fire loads, to the storage building referred to in the first example.

Whilst the investigation has afforded much insight into the problem of fire severity, and has given results comparable with those obtained by Ingberg, analysis of the results has been concerned mainly with the immediate uses. Full analysis of the data has yet to be made.

Among the factors yet to be taken into account are the effects of rates of combustion and loss of heat on the equivalent severity and on the shape of the temperature gradient, as affecting failure.

APPENDIX V

SUMMARY OF PROVISIONS OF MINISTRY OF HEALTH MODEL BYE-LAWS FOR SPACING OF CERTAIN CLASSES OF BUILDINGS

The following Tables summarize existing provisions for protection against exposure hazard which are now in force in most parts of England and Wales. The relative provisions for Scotland are contained in the Model Bye-laws made under Section 70 of the Housing (Scotland) Act 1935.

METHOD OF CONSTRUCTION	RESTRICTION ON SIZE	REQUIREMENTS AS TO SPACING
	Buildings for Storage, Agricultural Buildings, etc.	
Bye-laws not applicable to* construction.	Not more than 30 ft. in height and 125,000 cu. ft. capacity.	Not less than 8 ft. from any street and 30 ft. from boundary of adjoining lands or premises and from other buildings.
	Exceeding 30 ft. in height *or* 125,000 cu. ft. capacity.	Not less than 20 ft. from any street and 50 ft. from boundary of adjoining lands and premises and from other buildings.
	Exceeding both 30 ft. in height and 125,000 cu. ft. capacity.	Not less than 30 ft. from any street and 60 ft. from boundary of adjoining lands and premises and from other buildings.
	One-Storey Buildings not for Human Habitation	
Bye-laws with respect to* walls not applicable, but walls to be so constructed as to provide a suitable degree of fire resistance and due stability.	Not more than 30 ft. in height: and Not more than 2000 cu. ft. capacity.	Not less than 10 ft. from boundary (other than street).
	Exceeding 2000 cu. ft. but not more than 15,000 cu. ft. capacity.	Not less than 15 ft. from boundary (other than street).
	Exceeding 15,000 cu. ft. but not more than 80,000 cu. ft. capacity.	Not less than 30 ft. from boundary (other than street).
	Building of Warehouse Class (Warehouse or Factory)	
External walls with combustible frame and building constructed to have suitable degree of fire resistance.		Not less than 50 ft. from boundary of adjoining street or lands, or premises comprising buildings, or from any other building.

* These requirements apply to all buildings intended for the purpose mentioned, whether constructed of combustible materials or of incombustible materials, if they do not comply with the bye-laws.

METHOD OF CONSTRUCTION	RESTRICTION ON SIZE	REQUIREMENTS AS TO SPACING
Domestic Buildings (including Shops and Offices but not Public Buildings)		
Roof covering of combustible material.		Building to be twice its height from the nearest boundary and from any other building.
A. Walls : (a) constructed of incombustible material. (b) with framework of incombustible material, or of oak, teak, or other hard timber alone or in combination with incombustible material. (c) with framework filled with or externally covered with incombustible material.	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 cu. ft. in capacity ; no building in a block to exceed 18,000 cu. ft. in capacity.	Building to be not less than 5 ft. from boundary (other than a street) if its capacity does not exceed 18,000 cu. ft., or 10 ft. if capacity is greater.
B. Walls constructed of framework of timber, or of timber in combination with incombustible materials.	Buildings limited to three storeys. Not more than four buildings in a block (with incombustible party walls).	Building to be not less than 8 ft. from boundary (other than a 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).
C. Walls constructed of materials other than those at A or B above.	Single buildings or pair of buildings only (with incombustible party wall). Not exceeding two storeys high. No single building to exceed 36,000 cu. ft. in capacity ; no building in a pair to exceed 18,000 cu. ft. in capacity.	Building to be not less than 10 ft. from boundary (other than a street) if its capacity does not exceed 18,000 cu. ft., or 20 ft. if the capacity is greater.

APPENDIX VI

FIRE RESISTANCE GRADINGS OF ELEMENTS OF STRUCTURE

The fire resistance gradings of elements of structure given in the following Tables are based mainly on the results of tests carried out in accordance with the methods of test laid down in *B.S.* 476–1932 for Fire Resistance, etc. In the case of non-load-bearing walls and partitions, use has also been made of the results of American tests quoted in Report No. B.M.S. 92 of the Sub-Committee on Fire Resistance Classification of the Central Housing Committee of the United States Department of Commerce, which are based on the results of tests carried out substantially in accordance with the Standard American test for Fire Resistance (American Standard Specifications for Fire Tests of Building Construction and Materials, A.S.A. No. A 2, 1934).

The main features of the tests are described below:

BRITISH STANDARD TEST FOR FIRE RESISTANCE

The term fire resistance is defined in the Standard as "a relative term used to designate that property by virtue of which an element of structure as a whole functions satisfactorily for a specified period whilst subjected to prescribed heat influence and load." The Standard lays down the method of testing elements of structure to determine the period for which various elements will so function. Briefly, the test conditions are as follows. The test shall be made, where possible, on a full size element of structure, but if the dimensions normally exceed 10 ft. by 10 ft. a representative portion not less than 10 ft. by 10 ft. may be used; columns and beams exceeding 10 ft. long shall be tested in a length not less than 10 ft. If the structure is restrained in practice it shall be similarly restrained in the test; if unrestrained in practice it must be similarly tested. Load-bearing elements shall be tested whilst carrying one and a half times the design load; non-load-bearing elements are required to withstand (except in the case of glazing) an impact test, and for classification in higher grades the load is re-applied 48 hours after completion of the firing.

The element is subjected to heat applied in such a way that the furnace temperature conforms with a standard time temperature curve, which is designed to represent, as far as possible, average temperature conditions in building fires. It must be realized that actual fires vary widely in this respect; in some cases the temperature increases more rapidly than the standard, in others more slowly.

In the tests where an element is exposed to fire for 2 hours or more, the structure must be subjected at the end of the heating period to a standard jet of water for 1 minute for every hour of exposure.

An element of structure may then be classified in one of five grades as follows:

Grade	A—Compliance	with	test	conditions	for	6	hours.
,,	B—	,,	,,	,,	,,	4	,,
,,	C—	,,	,,	,,	,,	2	,,
,,	D—	,,	,,	,,	,,	1	hour
,,	E—	,,	,,	,,	,,	½	,,

in accordance with the length of time during which the following conditions are satisfied:

a. For walls, floors, and other elements of structure which function as separating structures and are required to resist the passage of fire from one space to another:
   i. the average temperature on the unexposed face shall not increase at any time during the test by more than 250° F. (139° C.) above the initial temperature, and shall not exceed 300° F. (167° C.) above the initial temperature at any point; and
   ii. cracks, fissures, and other orifices through which flame can pass shall not develop; and
   iii. the structure shall remain rigid and not collapse.

b. For columns and other elements of structure which serve only the function of carrying loads:

   The structure shall remain rigid and not collapse.

In the case of separating elements such as fire resisting doors, shutters, and glazing, criterion of failure (i) may be disregarded, so that the temperature on the unexposed face may increase to any value without failure of the door.

AMERICAN STANDARD TEST

The British Standard Test procedure follows, in all its major features, the corresponding American test, but there are certain important points of difference which make it difficult to make full use of the extensive results obtained in America.

Of the points of difference, the difference in the load applied to load-bearing elements of structure during the firing period is the most important. In the American test the element is loaded in such a manner as to develop the working stresses contemplated by the design. A different procedure is also adopted in respect of the water test and re-load test. Whilst it is possible, therefore, to make use of American test results on non-load-bearing elements the results on load-bearing elements must be considered in relation to the probable effects of increased loads required by the British test, which may be important in certain cases but accurate data are lacking.

FIRE RESISTANCE GRADINGS

The Tables give minimum requirements for elements of structure which comply with the indicated grades of fire resistance. It must be appreciated that the grades are not necessarily the actual periods for which the element would comply with the test conditions. In cases where standard thicknesses, for example, of bricks or blocks have been adopted by specification, the requirements are given in terms of the minimum standard thickness which attains the required grade. Thus, a nominal 9 in. brick wall is required for 4 hours fire resistance although it will comply with test conditions for at least 6 hours. The Tables are not intended to be comprehensive; they include only the more common systems of wall, floor construction, etc., and it must be appreciated that, subject to other requirements being satisfied, any system which affords the desired grade may be used.

MATERIALS AND CONSTRUCTION

In all cases where British Standards for materials have been issued, it is assumed that the material used in the element conforms with the specified requirements. In respect of reinforced concrete, the requirements for concrete and steel and the design of the element are assumed to be generally in conformity with the rules set out in the Report of the Reinforced Concrete Structures Committee of the Building Research Board dated July 1933. Structural steelwork is assumed to be designed generally in accordance with *B.S.* 449–1937 for the use of Structural Steel in Buildings.

Concrete Aggregates

The nature of the coarse aggregates used in concrete has an important bearing on the fire resistance attained by the element, and for practical purposes they may be considered in two broad groups. The first group, comprising those aggregates which show good behaviour at high temperatures, includes, for the most part, materials which in the course of their history have been subjected to heat, *e.g.* crushed brick and other burnt clay aggregates, foamed slag, pumice, etc.; but limestone may also be included in this class. As foamed slag and pumice aggregates are superior to the other materials of this class when used for certain types of wall units, it is convenient to separate them from the others of this group, which will be described generally as Class 1 aggregates. The second main group consists essentially of siliceous aggregates and includes normal flint gravel aggregate and most crushed natural stone other than limestone. These will be called Class 2 aggregates.

The following classification of aggregates is therefore used in the Tables:

Class 1 (a) Foamed slag, pumice.

„ 1 (b) Blast furnace slag, crushed brick, and burnt clay products, well-burnt clinker, crushed limestone.

„ 2 Siliceous aggregates generally, *e.g.* flint, gravel, granite and all crushed natural stones other than limestone.

It will be noted that this classification takes account only of fire resistance. The suitability of the material from other standpoints must, of course, be considered, and clearly where structural requirements are demanded the aggregates must comply with the rules mentioned in the report previously referred to.

PLASTER

In general, plaster applied directly to brickwork and concrete shows variable behaviour when exposed to fire. Spalling may occur at an early stage and any protective effect is lost. In general it seems that, in the case of walls, it would be unwise to make allowance for the plaster on both sides, and accordingly the effect of a single thickness is considered when walls are plastered on both sides.

APPLICATION TO PRACTICE

It must be appreciated that as the tests are made on elements of structure only, careful consideration must be given when making use of the data as to the manner in which the elements are connected to one another, so as to ensure that the full fire resistance is developed.

Walls and Partitions

Proposed gradings for walls and partitions are given in Table 1. Those for masonry walls are based on tests on elements laid in cement or cement lime mortar. The type of mortar used does not have an appreciable effect on the endurance of thicker walls, in which failure usually occurs by temperature rise, but the effect of mortar may be important in thinner walls where failure by buckling is more possible. Data on the effect are lacking and the gradings are based on the assumption that for walls less than 8½ in. thick a cement or cement lime mortar not less than 1:4 cement sand or 1:2:9 cement lime sand is used. The loads applied to masonry walls were based on the allowable stresses given in the second schedule to the Ministry of Health Model Bye-laws, Series IV, 1937.

The tests were made on walls 10 ft. by 10 ft. as required by *B.S.* 476–1932, and gradings are based on that size. It is clear, however, that the results may not apply to walls of equal thickness but of greater dimensions. When a wall is heated on one side it expands and bulges, and the stability of the wall will be determined by its length, height, and thickness, the load imposed on the wall and the degree of fixity at the edges. The effects which these factors may have on the grade of fire resistance cannot be properly assessed from the test results owing to the limits imposed by the size of the furnace.

In the case of load-bearing masonry walls, general requirements for strength and stability would usually ensure a thickness in excess of that necessary to attain the desired grade (see, for example, the thickness of walls in Model Bye-laws).

On the other hand, whilst there will be limitations on the dimensions of non-load-bearing walls from the standpoint of structural stability, these limits will in general be much greater than the maximum dimension of the test panels, although in the majority of cases the height will not greatly exceed 10 ft. The height is, however, likely to have a greater bearing on the actual grade of fire resistance than the length, and accordingly where the dimensions of any panel exceed the height or greatly exceed the length of the test panel, consideration should be given to the use of the thickness required for the next higher grade of fire resistance.

ALLOWANCE FOR THICKNESS OF PLASTER

In certain instances fire resistance gradings are given for walls both with and without plaster. In the former case it is assumed that a gypsum or cement or cement lime plaster is applied on both sides of the wall to a minimum thickness of ½ in. on each side. Gypsum plaster mixes should conform to the makers' recommendations; Portland cement or lime cement mixes should be not leaner than 1:4 cement sand or 1:2:9 cement lime sand respectively.

PLASTERED HOLLOW PARTITIONS

In the case of hollow partitions consisting of plaster on expanded metal lathing or wood lathing, no attempt has been made to differentiate between the thicknesses required of the various kinds, for in practice very small differences in thickness will not usually be determinable.

TABLE 1. WALLS AND PARTITIONS
FIRE RESISTANCE GRADINGS

CONSTRUCTION AND MATERIALS		GRADE A 6 HRS.	GRADE B 4 HRS.	GRADE C 2 HRS.	GRADE D 1 HR.	GRADE E ½ HR.
		MINIMUM THICKNESS IN INCHES EXCLUSIVE OF PLASTERING TO ATTAIN INDICATED GRADE				
Solid bricks of clay, concrete or sand-lime	Solid wall. No plaster Solid wall plastered on both sides	8½ 8½	8½ 8½	8½ 4½	4½ 4½	4½ 4½
	Cavity Wall. No plaster (2 in. Cavity)	10½	10½	10½	—	—
Solid concrete blocks (conforming to *B.S.* 492)	*Class* 1 (*a*) *Aggregates* Solid Wall. No plaster Solid Wall plastered on both sides	 — —	 — 4	 4 3	 3 2	 2½ 2
	Class 1 (*b*) *Aggregates* Solid Wall. No plaster Solid wall plastered on both sides	 — —	 — —	 4 4	 3 2½	 2½ 2
	Class 2 *Aggregates* Solid Wall. No plaster Solid Wall plastered on both sides	 — —	 — —	 — 4	 4 3	 3 2
Reinforced concrete*	Class 1 Aggregates	8	6	4	3	3
	Class 2 Aggregates	9	7	4	3	3
Hollow clay blocks (A).† Shells not less than ¾ in. thick	All plastered ½ in. thick on both sides 1 cell in thickness; not less than 50% solid 1 cell in thickness; not less than 30% solid 2 cells in thickness; not less than 50% solid 2 cells in thickness; not less than 45% solid	 — — — —	 — — — —	 — — 8½ —	 4 6 4 6	 3 — — —
Hollow concrete block (A) (conforming to *B.SS.* 728 or 834)	Plastered ½ in. thick on both sides. 1 cell in wall thickness *Class* 1 (*a*) *Aggregates* *Class* 1 (*b*) *Aggregates* *Class* 2 *Aggregates*	 — — —	 8¾ 8¾ —	 4 4½ —	 2½ 3 8¾	 — 2½ 3
Solid blocks of gypsum (A)	No plaster ½ in. plaster both sides	— —	— —	4 3	3 2	2 2

* Walls to be reinforced vertically and horizontally at not more than 6 in. centres, and reinforcement to be not less than ·2% of volume.
Walls less than 5 in. thick to have single layer of reinforcement in middle of wall.
Walls more than 5 in. thick to have two layers of reinforcement, not less than 1 in. from each face.

† Gradings of elements followed by (A) are derived mainly from American sources.

CONSTRUCTION AND MATERIALS		GRADE A 6 HRS.	GRADE B 4 HRS.	GRADE C 2 HRS.	GRADE D 1 HR.	GRADE E ½ HR.
		MINIMUM THICKNESS IN INCHES EXCLUSIVE OF PLASTERING TO ATTAIN INDICATED GRADE				
Hollow blocks of gypsum (not less than 70% solid) (A)	No plaster	—	—	4	3	2
	½ in. plaster both sides	—	—	3	2	2
Solid wood wool slabs	½ in. plaster both sides	—	—	3	2	2
Solid plaster	Central reinforcement of metal lath on steel rods or studs	—	—	—	2	2
Plasterboard supported top and bottom edges in steel channels	⅝ in. gypsum plaster on both sides	—	—	—	¾	—
Glass blocks	Not exceeding 5 ft.×5 ft. with expansion joint	—	—	—	4	—

HOLLOW PARTITIONS		GRADE OF FIRE RESISTANCE (HOURS)
Plaster * on expanded metal on steel or timber studding (A)	*Gypsum, Portland Cement or Cement Lime Plaster* ½ in. thick on each side ¾ in. thick on each side	 ½ 1
Plaster on wood lathing on timber studding (A)	*Gypsum, Portland Cement or Cement Lime Plaster* ½ in. thick on each side	 ½
Plasterboard with or without gypsum plaster on timber studding	⅜ in. plasterboard with $\frac{3}{16}$ in. neat plaster	½
	½ in. plasterboard with no plaster	½
	½ in. plasterboard with ⅝ in. plaster ¾ in. plasterboard	1 1
Fibreboard on timber studding (A)	½ in. fibreboard with ½ in. plaster	½

* Thickness of plaster measured from outer face of lathing.

Floors

Proposed gradings for floors are given in Table 2 and relate to the resistance to fire from below. Experience in actual fires suggests that exposure to fire of the upper side of an incombustible floor is not as severe as the conditions on the soffit, and it is reasonable to expect that any floor which successfully resists exposure from below will be adequate to prevent penetration from above. Timber joist floors of special construction may afford relatively high resistance to exposure on the soffit, but fire on the upper surface will ignite board finishes and the fire will spread to lower floors. A complete burn-out of the building may then result.

The fire resistance of concrete floors is largely influenced by the restraint around the edges. The tests were made on floors supported in a frame which offered full restraint and was not subjected to heat. In actual fires the degree of restraint will vary widely and the frame will be subject to the same heating as the floor. Tests on simply supported concrete floors indicate that better resistance is attained than in the case of the restrained floor, but in practice it is found that failures of concrete floors which can be regarded as simply supported are due to absence of or inadequate continuity reinforcement, the whole panel falling often without serious damage to the slab itself.

The tests on solid reinforced concrete floors indicate that the thickness of the reinforcement has an important effect on the fire resistance, especially in the case of thinner floors. Much further research seems necessary to elucidate the effect of variable factors, and the gradings proposed below are based partly on test results and on experience of the behaviour of floors in actual fires.

CEILINGS

The fire resistance of floors can be increased considerably by the addition of a properly fixed ceiling. One example may be quoted. A reinforced concrete floor of flint gravel aggregate which would fail in the test at about ½ hour was given, on the soffit, a coat of sprayed asbestos 1 in. thick. This floor withstood without damage a 4-hour test.

Plaster applied directly to the soffit of the floor is unreliable, and the minimum ceiling from which added protection can be expected consists of plaster on expanded metal, securely fixed to the main slab, or its equivalent. Except in the case of timber floors no test data are available, but it may be noted that in the Canadian code a reduction up to 1 in. in slab thickness is permitted if a ceiling consisting of ¾ in. gypsum plaster on metal lath or equivalent is fixed.

Table 2. Floors and Roofs

Fire Resistance Gradings

CONSTRUCTION AND MATERIALS	GRADE A 6 HRS.	GRADE B 4 HRS.	GRADE C 2 HRS.	GRADE D 1 HR.	GRADE E ½ HR.
	MINIMUM THICKNESS IN INCHES FOR INDICATED GRADINGS				
Concrete Floors or Roofs					
(a) *Filler Joist.* Maximum spacing of joists as allowed for structural requirements. Any aggregate.					
Minimum slab thickness	7	6	5	4	3½
Minimum cover on flanges of joists					
Top	—	1	1	—	—
Bottom	—	1	1	½	½
(b) *Solid Reinforced Concrete Slab*					
Minimum slab thickness	7	6	5	4	3½
(c) *Hollow Tile*					
Minimum thickness of incombustible material, *i.e.* thickness of concrete slab and of solid material in tiles	—	5	3½	3	2½
Minimum cover to steel	—	1	¾	¾	½
Wood Floors or Roofs					
⅞ in. boards on wood joists 9 in. by 2 in. (nominal)					
(i) T. and G. boarding with wood lath and plaster ceiling (ii) Plain edge boarding with metal lath and plaster ceiling (iii) T. and G. boarding with wood lath and plaster pugged with 3 in. ashes (Scottish practice)	Mimimum thickness of plaster				⅝ in.

Structural Steelwork

The data in Table 3 are given in terms of the minimum thickness of protection necessary to attain the indicated grade, the thickness being measured as shown by the letter "t" in Fig. 7.

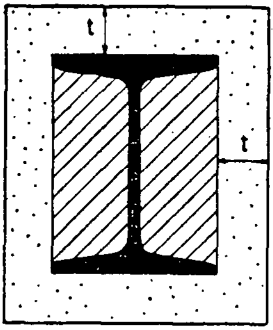


Fig. 7. METHOD OF MEASURING THICKNESS OF PROTECTION

The protection is said to be solid when the whole of the void shown shaded in Fig. 7 is filled with protective material; a hollow protection is that in which the void is left empty.

Rivet heads may lie within the specified thickness of solid protection.

The actual tests were in general made on protected 8 in. by 6 in. members, and the protection required to attain any grade relates strictly to that size of column only. There is evidence, both in practice and from theoretical considerations, that columns of larger size with solid protection will have greater fire resistances on account of the greater mass of material which is involved, all of which must be heated before failure can occur. There is, however, a greater tendency to spalling of concrete from large flat areas of steel, and although this may largely be minimized by adequate reinforcement, it is considered that until data are available the same thicknesses of protection should be required for all column sizes.

Table 3. Steel Columns and Beams
Protection Required

Mesh reinforcement suitable for reinforcing concrete protection is 6 in. by 4 in. mesh, 13 S.W.G. Wire. Wire reinforcement may consist of ⅛ in.–13 S.W.G. iron wire loosely bound round the steel at 4 in.–6 in. pitch.

CONSTRUCTION AND MATERIALS	GRADE A 6 HRS.	GRADE B 4 HRS.	GRADE C 2 HRS.	GRADE D 1 HR.	GRADE E ½ HR.
	MINIMUM THICKNESS IN INCHES OF PROTECTION OUTSIDE STEEL FOR INDICATED GRADINGS				
Solid Protection Brickwork with filling of brick and mortar, all properly bonded	4½	3	2	—	—
Concrete Not leaner than 1 : 2 : 4 Mix. Reinforced centrally with steel mesh or with wire — Class 1 aggregates	4	2½	1½	1	—
Concrete — Class 2 aggregates	4	2½	2	1	—
Gypsum Concrete (7 parts gypsum, 1 part wood chips, poured *in situ*) (A)	3	2	1½	1	—
Hollow Clay Tile with interior filling of concrete—thickness of solid material	—	—	—	—	1½
Foamed Slag blocks with interior filling of concrete or blocks and mortar. Wire reinforcement in every horizontal joint	4	2½	2	2	—
Gypsum Blocks with interior filling. Wire reinforcement in every horizontal joint	3	2	—	—	—
Sprayed Asbestos	—	2	1	½	¼
Hollow Protection Brickwork or solid clay blocks with wire reinforcement in every horizontal joint	—	4½ (Reinforced every fourth joint)	3	2	—
Foamed Slag blocks with wire reinforcement in every horizontal joint	4	3	2	2	—
Gypsum Blocks with wire reinforcement in each horizontal joint (A)	—	3	2	2	—
Moulded Asbestos held in position with nichrome wire	3½	2½	1½	1	—
Plaster on expanded metal lathing wired to joist with wire netting over first coat	—	—	—	1	—
Plaster on expanded metal lathing	—	—	—	—	¾
Gypsum plaster on plasterboard with wire binding	—	—	½ in. Plaster on ¾ in. Plasterboard	½ in. Plaster on ¾ in. Plasterboard	⅜ in. Plaster on ⅜ in. Plasterboard

Note: All methods of protection may not be suitable for beams. No data for solid steel columns are available.

Reinforced Concrete Columns

The data which are available for grading reinforced concrete columns are by no means adequate, and the Committee has requested the Building Research Station to put in hand a comprehensive series of tests designed to obtain more fundamental information than is at present available, on the effect of the various factors which influence the grading.

Reference has already been made to the effect of type of aggregate, and where high grades of resistance are desired the best available aggregate should be employed. The use of high grade concretes, with correspondingly high stresses and reduced sections, results in a greater percentage reduction in the strength of a member after exposure to fire than is the case for ordinary grade concretes, particularly when the whole sectional area is utilized for carrying load. Similarly, greater percentage reduction of strength is to be expected under severe fire conditions with the use of high percentages of steel reinforcement having normal cover, especially if spalling of the concrete cover occurs. The effect of intense fire is to reduce the strength of cold worked steel and ordinary steel to approximately the same level, and this factor should be borne in mind if high resistance to fire is desired. The use of thin deep beams permits more rapid penetration of heat throughout the member, with consequent weakening of the whole section. A beam with a greater width/depth ratio would retain a stronger core for similar fire conditions. These and other factors must be taken into account in developing a proper system of grading, and it is clear that the fire resistance offered by a reinforced concrete member is intimately linked with its design; the flexibility in design offered by reinforced concrete permits considerable variation in practice. The tests referred to above are designed to elucidate the effect of the various factors and to establish the grading on a proper basis.

The gradings suggested in Table 4 must therefore be regarded as interim, pending the completion of the tests. They are based on available tests carried out in accordance with *B.S.* 476–1932 and on consideration of American practice.

TABLE 4

TENTATIVE GRADINGS FOR REINFORCED CONCRETE COLUMNS DESIGNED IN ACCORDANCE WITH THE CODE OF PRACTICE FOR REINFORCED CONCRETE

SIZE OF COLUMN	TENTATIVE GRADE OF FIRE RESISTANCE (HOURS)	
(Overall Diameter of Round Columns or Side of Square Columns)	Class 1 Aggregates (Limestone, Blast Furnace Slag)	Class 2 Aggregates
10 in. up to 12 in.	2	1 hr. *or* 2 hours if light 2 in. mesh reinforcement placed centrally in concrete cover to main reinforcement.
Over 12 in. up to 20 in. (Data not available for columns more than 20 in. diameter or side).	4	2 hrs. *or* 4 hours if light 2 in. mesh reinforcement placed centrally in concrete cover to main reinforcement.

APPENDIX VII
METHOD OF TESTING THE SPREAD OF FLAME ON SURFACES

EXPLANATORY

The test is intended to differentiate between the rates at which flame will spread over the surfaces of different types of lining materials, and therefore measures a different property from that of fire resistance or even of inflammability as defined in *B.S.* 476. In order to make the test conform to conditions as similar as possible to those which may occur in practice, the rate of spread of flame is measured on material placed in a vertical plane and subjected to radiant heat as well as to contact with a flame. Materials under these conditions may be classified in a different order from that which would be obtained in the absence of radiant heat. The test consists essentially in exposing strips of board of standardized dimensions to radiant heat under standardized conditions in such a way that the intensity of radiation is high at one end of the board but is progressively reduced along the length of the board (see Fig. 8). At the same time as the board is exposed to the

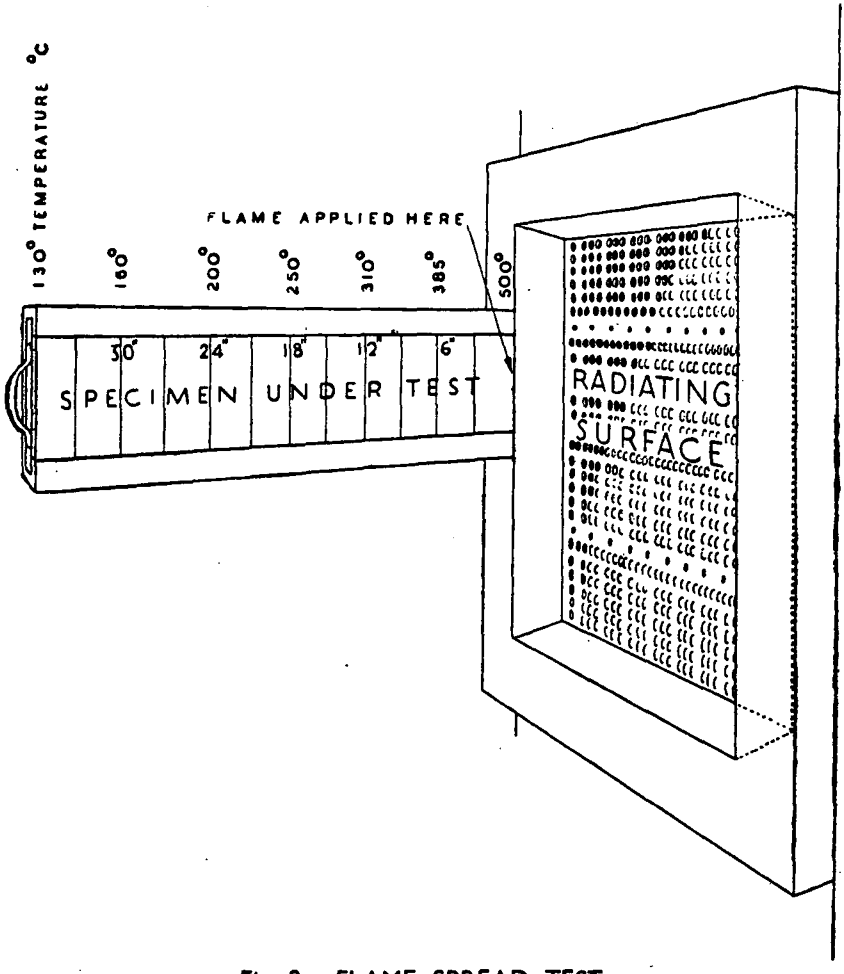


Fig. 8. FLAME SPREAD TEST

radiant heat, a standardized gas flame is applied at the hot end, and observations are made of the rate of sideways spread of flame over the surface of the material.

The test also gives an indirect indication of the degree of susceptibility to ignition of the surface. It may be assumed that before the surface can be readily ignited by a flame, it would have to be at not less than the radiant heat temperature of the point at which the flame died out in the test.

TEST PROCEDURE

At least three test-pieces, each 36 in. by 9 in. by the normal thickness, from each sample, are required for the test, but a greater number may be required at the discretion of the testing authority, if the tests on the first three show marked variability. Before test the edges, together with a strip 1½ in. wide from the edges on the unexposed face, are painted with sodium silicate paint of the composition defined in *B.S.* (ARP) 39, after which the specimens are conditioned to a moisture content in equilibrium with air at 50–70° F. and 55–65 per cent relative humidity.

The test-piece, placed with its long axis horizontal and its face vertical, is exposed to radiant heat of an intensity varying along the length in such a way that the temperature of a gold disc thermocouple placed in the same position and the same plane as the test-piece will be raised to the following temperatures within—3 per cent:

Distance from hotter end (in.)	0	3	6	9	12	15	18	21	24	27	30	33	36
Temperature (° C.)	500	435	385	345	310	280	250	225	200	180	160	145	130

A suitable gold disc thermocouple consists of a 1 in. diameter gold disc, 35 S.W.G., silver-soldered to a chromel-alumel thermocouple made from 26 S.W.G. wire. The gold disc is well blackened on the thermocouple side with platinum black or lampblack, and this side is exposed to the radiant heat. The other side of the disc is maintained bright and polished.

Support for the specimen is provided by nailing it to a backing of wood, faced with ½ in. thick asbestos millboard in such a way that free burning can take place on the face of the specimen without obstruction from other supports.

The room in which the test is made should be substantially free from air draughts.

The specimen is brought from air temperature into its position of exposure to the full intensity of radiant heat within 5 seconds, and is immediately ignited at its high temperature end by means of a vertical luminous gas flame, 7 in. long, issuing from a ⅜ in. diameter orifice placed not more than ¼ in. forward from the surface and lower edge of the specimen.

OBSERVATIONS

As soon as the igniting flame is in contact with the specimen, observations are made of the time of spread of the flame front for measured distances along the top and bottom edges of the specimen. Measurements are continued until the flame front has either traversed the whole surface or, if this does not take place, until the flames have died out. Similar observations are made on all specimens of the sample.

COMPUTATION OF RESULTS

The following procedure is adopted for determining the mean distance of spread of flame:

i. If the distance of spread of flame does not exceed 33 in. on any of the specimens, the mean value of the maximum distance of spread of flame along the top and the lower edges of all the test-pieces tested in the sample is taken.

ii. If the distance of spread of flame exceeds 33 in. on any one specimen a mean curve of rate of spread with time is obtained in the following manner:

A curve of the distance of spread of flame with time is drawn for each specimen by plotting the mean value of the distances along the top and bottom edges against time. If flaming ceases along one edge while continuing along the other, the distance at which flaming ceases on the one edge is used in determining the mean of the additional results from the other edge.

From the curves for each specimen a mean curve is constructed for the whole group. As before, if the curve for one specimen ceases at some particular distance while the remainder continue, the value at this distance is still used to determine the mean of all specimens, *i.e.* in effect the curve is continued as a line parallel to the time ordinate, and averages determined in the normal way.

CLASSIFICATION

Both surfaces of a material should be tested and the material described by reference to the results on each surface which should be classified in one of the following groups according to their observed behaviour under test:

Class 1. *Surfaces of Very Low Flame Spread*
Those surfaces on which not more than 6 in. mean spread of flame occurs.

Class 2. *Surfaces of Low Flame Spread*
Those surfaces on which, during the first 1½ hours of test, the mean spread of flame is not more than 15 in. and the final spread does not exceed 18 in.

Class 3. *Surfaces of Medium Flame Spread*
Those surfaces on which during the first 1½ minutes of test the mean spread of flame is not more than 15 in. and during the first 10 minutes of test is not more than 33 in.

Class 4. *Surfaces of Rapid Flame Spread*
Those surfaces on which during the first 1½ minutes of test the mean spread of flame is more than 15 in. and during the first 10 minutes of test is more than 33 in.

GLOSSARY OF TERMS

These definitions of terms are intended only to cover their use in this Report

ACCESSIBILITY. A term used, in general, to denote the location of a building or division with respect to the streets or open spaces of specified width on which the building or division abuts, and which afford ease of entry and attack by firemen in the event of fire; and, specifically, the length of external wall required to abut on a street or streets expressed as the number of feet per 1000 sq. ft. of floor area, or that proportion of the perimeter of a building or division which abuts on a street or streets.

BASEMENT. Any storey of a building or of a division of a building which is next below the ground storey.

COMBUSTIBLE CONTENT. Means material not conforming to the standard of incombustibility laid down in *B.S.* 476–1932, contained in any building, division, or compartment, together with material similarly defined forming any part of the construction.

COMPARTMENT (OR CELL). A part of a building or division separated from the remainder by walls and/or floors having sufficient grade of fire resistance to resist a complete burn-out of the contents.

CUBICAL CAPACITY

a. *Of a Compartment.* Means the space contained by the inner structural surfaces of the fire resisting walls enclosing the compartment and either by:
   (i) the inner structural surfaces of the floors enclosing the compartment, or
   (ii) of the floor and the lower surface of any incombustible roof, or
   (iii) of the floor and upper surface of any combustible roof.

b. *Of a Division.* Means the space contained by the inner structural surfaces of its enclosing walls, the upper surface of the floor of its lowest storey, and either by the lower surface of any incombustible roof over the division or by the upper surface of any combustible roof over the division.

DIVISION. A part of a building separated from the remainder of a building by a division wall or walls.

DIVISION WALL. Means a fire resisting wall carried vertically throughout a building from the lowest level of any basement or sub-basement bounded by the wall, and continued 18 in. in the case of occupancies of low fire load, or 3 ft. in the case of other occupancies, above any portion or portions of a roof which, within the specified distance measured horizontally, are not of a specified grade of fire resistance, the distance above the roof being measured at right angles to the surface of the roof covering.

ELEMENT OF STRUCTURE. Is a part of the structure of a building as defined in *B.S.* 476–1932, *e.g.* load-bearing and non-load-bearing walls, floors, columns, glazing, etc.

EXPOSED BUILDING. Is a building which may be in danger of taking fire by reason of fire in another building or other source external to the building.

EXPOSING BUILDING. Any building which, being on fire, may endanger any other building.

FIRE LOAD. The amount of heat expressed in B.Th.U's. per sq. ft. of floor area which would be generated on any one floor by complete combustion of the combustible contents, calculated on the assumption that the material is uniformly distributed over the total area under consideration.

FIRE PRECAUTIONS. Any measures taken to reduce the fire hazard. They include both preventive and protective measures.

FIRE PROTECTION. Measures taken to reduce the danger to the occupants of a building, to the public, and to fire fighting personnel, and to minimize the damage to a building and its contents, in the event of an outbreak of fire.

FIRE PREVENTION. Measures taken to restrict the risk of an outbreak of fire.

FIRE RESISTANCE. (Of an Element of Structure; see *B.S.* 476–1932.) The term fire resistance is a relative term used to designate that property by virtue of which an element of a structure as a whole functions satisfactorily for a specified period whilst subjected to prescribed heat influence, load, and, in certain cases, water.

FIRE RESISTING FLOOR. Means a floor having a standard of fire resistance specified in terms of a Grade laid down in *B.S.* 476–1932, any openings in which are protected openings.

FIRE RESISTING WALL. Means a wall having a standard of fire resistance specified in terms of a Grade laid down in *B.S.* 476–1932, any openings in which are protected openings.

FIRE SEVERITY. A characteristic of a fire determined by the effective duration and the temperature reached at various times during the fire. It is indicated by the form of the time-temperature curve.

FLOOR AREA

a. *Of a Compartment.* Means the area of the floor (or of the several floors) bounded by the inner structural surface of the fire resisting walls enclosing the compartment.

b. *Of a Division.* Means the maximum area on any one floor bounded by the inner structural surfaces of the walls enclosing the division.

GROUND STOREY. Is that storey of a building or division of a building to which there is an entrance from a street, the upper surface of the floor being at any part not more than 4 ft. below the level of the adjoining pavement.

HEIGHT. Of a building or division of a building, means the vertical measurement from the highest level of the pavement or ground adjoining, to the underside of the ceiling of the top storey, or, if all or part of the topmost storey is in the roof space, to the highest point of the underside of the ceiling, or, if there is no ceiling, to the underside of the tie-beam or collar beam.

PROTECTED OPENING. Means an opening in an internal fire resisting wall or floor which may be closed by doors, shutters, or other protection of a specified grade of fire resistance.

SEPARATING WALL. Means a wall separating buildings and having a fire resistance of not less than 4 hours carried vertically throughout the building from the lowest level of any basement or sub-basement bounded by the wall, and continued to a height of 18 in. in the case of occupancies of low fire load or 3 ft. in the case of other occupancies above any portion or portions of a roof which, within the specified distance measured horizontally, are not of the specified grade of fire resistance, the height being measured at right angles to the upper surface of the roof covering. In the case of one- and two-family dwellings, the fire resistance may be not less than 1 hour, and the wall need not in general be carried through the roof.

SHAFT. Means a space extending through or serving two or more successive storeys of a building, *e.g.* for the passage of goods or persons from one storey to another or to the roof space of roof surface.

SUB-BASEMENT. Any storey of a building or of a division of a building which is below a basement.

TRIM. Materials fixed in a permanent fashion on or around elements of structure, either as architectural treatment or for utility purposes not connected with fire resistance, *e.g.* skirtings, picture rails, architraves, panelling, wall linings.

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