POST-WAR BUILDING STUDIES
NO. 29

FIRE GRADING OF BUILDINGS

PART II
FIRE FIGHTING EQUIPMENT

PART III
PERSONAL SAFETY

PART IV
CHIMNEYS AND FLUES

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

LONDON: 1952
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 peacetime 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 as far as possible uniform direction and policy.

A list of the Reports in this Series 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, In 1945 We, your Joint Committee on the Fire Grading of Buildings, submitted Part I of our Report, and indicated then that we should later present three additional Parts dealing respectively with:

Fire Detection and Fire Fighting Equipment in Buildings (Part II).

Precautions relating to Personal Safety (Part III).

Chimneys, Flue Pipes and Hearths (Part IV).

We beg leave to present these Parts herewith.

With these we include three notes concerned with matters which fall within the scope of Part I, but which have been raised since its publication. Two of these are included in this volume as an Addendum to Part I and one as Appendix III.

We have thus completed the studies which we were asked to undertake under our Terms of Reference. We have held 10 meetings in full Committee and our working group and panels 71 meetings.

Fire protection requirements constitute a major part of building byelaws and have in the past proved a stumbling-block to developments in building practice. Although the changes incorporated in the last series of Model Byelaws issued by the Ministry of Health represented a major advance towards a rational basis, sufficient data were not then available for their full development; but advances in knowledge over the past ten years have filled most of the gaps sufficiently at least to enable the preparation of a comprehensive code of fire-protection to proceed. We are glad to note that provision is made in the general scheme of the Council for Codes of Practice for inclusion of a comprehensive chapter on Fire Precautions. We would urge early attention to the preparation of a nationally acceptable code of wide application, for, as we indicated in Part I, our Report is but a technical study of the problems.

We wish to express great appreciation of all that our secretary, Mr. R. C. Bevan, has done for us throughout the six years occupied by our enquiries. His contribution has fully justified the high traditions of the Building Research Station, particularly in the direction of research in uncharted fields.

We would also express appreciation of the help we have received from his colleagues in preparing the remaining parts; Mr. S. Jarvie, who was concerned with the preliminary drafting of Part III; Mr. D. K. Baron, who assisted in the preparation of Part IV; and, in particular, Mr. K. R. Lack, who entered into the work at a later and most difficult stage and gave valuable assistance in completing the whole document.

We are again indebted to the Fire Offices' Committee and to the Building Research Station for help and facilities at all times, and would refer especially to the courtesy of the Fire Offices' Committee in making available their room for our meetings. We are glad also to be able to acknowledge the helpful co-operation of the Joint Fire Research Organisation of the Department of Scientific and Industrial Research and Fire Offices' Committee, and of the Fire Offices' Committee Fire Protection Association.

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FIRE GRADING OF BUILDINGS
(PARTS II-IV)

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

In presenting these remaining Parts of our Report we wish to draw attention to the fact that they should be read in conjunction with Part I.[1] In that Part (Paragraph 2), it was noted that the Report attempts "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."

PART II. FIRE DETECTION AND FIRE FIGHTING EQUIPMENT IN BUILDINGS

GENERAL

1. In the Introduction to our Report (Part I, page 6), we stated that the fire hazard to life and property can be minimized by (*a*) fire prevention methods, *i.e.* those aimed at preventing outbreaks of fire—an aspect which was considered to be outside the scope of our Report, (*b*) fire protection methods, *i.e.* those adopted to minimize the spread of fire both within the building and to nearby buildings, and (*c*) providing for the escape and general safety of the occupants should an outbreak of fire occur. We considered that growth and spread of fire should be minimized and the risk to occupants reduced by a rational combination of two distinct methods, balanced and adjusted according to the risk involved; *viz.* by suitably constructing and planning a building having due regard to both internal fire and fire in adjacent buildings, *i.e.* "passive defence," and by providing means of extinguishing fire, *i.e.* "active defence." In Part I we dealt with the "passive defence" measures which should provide an acceptable standard of security against spread of fire, and made recommendations for the planning, construction and separation of buildings, and in Part III we deal with structural matters and planning in relation to the safety of the occupants. In this Part we consider and make recommendations for those provisions of "active defence" which should be regarded as a necessary part of the equipment of any building.

ACTIVE DEFENCE MEASURES

2. Active defence measures for extinguishing fire and minimizing its spread within buildings and to nearby buildings are normally provided by:

1. Alarm systems to warn the occupants of buildings and to summon assistance.
2. Equipping buildings with fire extinguishing appliances which operate automatically or are capable of immediate use by any active person on the spot.
3. The fire services using their own equipment and any apparatus and facilities provided in and around the buildings to assist them in their operations.

[1] *Post-War Building Studies, No. 20, Fire Grading of Buildings: Part 1, General Principles and Structural Precautions.*

3. Although statistical data are lacking, there is little doubt that a great proportion of outbreaks of fire in buildings are extinguished in their incipient stage by the occupants, or by automatic means where this type of apparatus is installed. This is an important aspect of the whole fire problem as, by markedly restricting the number of outbreaks which develop into extensive fires, the burden which would otherwise be imposed on structural precautions and the fire services is greatly relieved. The number of occasions when the occupants of buildings are endangered is also greatly reduced. When fires do reach a more advanced stage, the provision of suitable apparatus and facilities in and about the premises has in certain cases proved of great help to the fire services in reducing the extent of damage, especially in the higher and larger buildings.

4. Active defence measures are desirable in all buildings, and they will vary in extent with such factors as location, size, construction and class of occupancy of the building. Up to the present, general guidance as to what may be regarded as a reasonable and proper standard of such equipment and facilities has been lacking, although there are a few notable exceptions, for example the *Rules* of the Fire Offices' Committee, the Home Office *Manual of Safety Requirements in Theatres, etc.*, *Fire Precautions in Schools* (Home Office) and the Recommendations of the Electricity Commissioners on *Fire Risks at Generating Stations, etc.* There has, moreover, been little research work into methods of fire extinction, and as a result it has been found necessary in preparing this Part to rely even more on experience than in Parts I and III.

5. Effective defence measures are, of course, dependent to a large extent on the availability of a sufficient supply of water. Although some attempts have been made experimentally on a small scale to correlate the quantity of water needed to extinguish fire with the character and extent of the fires, it is not yet possible to approach the requirements for buildings on a fundamental basis, especially as practical considerations and the difficulties attendant upon fire fighting affect the question so largely. We have not considered it part of our duties to discuss this question in detail, and for our purpose we have assumed that suitable supplies of water will be available. Water is the most suitable fire extinguishing agent for dealing with fires in the great majority of occupancies with which we are concerned, but mention will be made of the circumstances in which other extinguishing agents are more appropriate. We may note, however, that where adequate mains supply is not available, attention should be paid to the installation of static supplies in tanks, or if ample natural resources are near, arrangements should be made whereby they may be readily available in case of fire. Hard ground for the access of fire service pumps should be provided to within a few feet from the surface of the water. It would be advisable to consult the local fire service in all cases where these supplies are provided.

FIRE SERVICES

6. Although it is not the function of this Report to consider the organization and equipment of fire services, they form an essential complement to the structural precautions recommended by us, and in arriving at our recommendations in Part I we assumed there would be a reasonably uniform standard of fire-fighting throughout the country, realizing that there will be differences in operating conditions, for example, between urban and rural areas. It is now necessary to be more explicit than in Part I and to detail the assumptions on which our recommendations were based and on which we shall base our further recommendations here.

FIRE DETECTION AND FIRE FIGHTING EQUIPMENT

The main operational functions of the public fire service are:

1. To rescue persons who may be cut off by fire or otherwise prevented from using the normal escape routes. Rescue from buildings up to 42 ft. high to the topmost floor is regarded as a normal function of the public fire service, but as indicated in Part III rescue cannot be regarded as a supplement to structural means of escape above that height, though it would always be attempted.
2. To extinguish fires in buildings expeditiously, and to minimize the extent of damage to the contents and the structure.
3. To protect buildings against fire spreading from nearby fires.

In addition advice is given on matters of fire protection in relation to fire prevention in buildings.

7. The operational functions are carried out by firemen using wheeled or floating pumps which are used to project water on to a fire, and mobile ladders of various types, of which the mobile escape ladder up to 50 ft. long and the turntable ladder up to 100 ft. long are the most important. The mobile escape ladder is primarily intended for the rescue of endangered persons, though it is often used for fire attack; the purpose of the turntable ladder is to enable jets of water to be directed on to the roofs and upper floors of high buildings, though it is sometimes used for rescue work. The public fire service is also equipped with apparatus for dealing with special fire risks, *e.g.* inflammable liquids, electrical apparatus.

8. In highly concentrated warehouse, commercial and industrial areas, we assume there will be at least three fire appliances at the fire within 5 minutes from the time of call, and where necessary an attendance of 10 within 20 minutes. In other areas in the larger towns the numbers will be 2 and 5 respectively, in medium-sized towns 1 and 3, and in small towns and villages we assume that a fire appliance will reach the scene in less than half an hour. We have also assumed that at least in built-up areas, the fire will be observed at a reasonably early stage and that facilities will be available for a prompt call to be made. We assume, too, that at least one of the first appliances to arrive will be equipped to effect rescues from floor levels up to 42 ft. high; and in concentrated areas and in the larger towns, one at least of the fire fighting appliances arriving at an early stage will be a turntable ladder capable of projecting into a building a jet of water from heights up to 100 ft. above ground level.

9. We have not considered it part of our function to deal with the mobile equipment of "private" or "industrial" fire brigades.

PROVISION OF EQUIPMENT IN BUILDINGS

10. The provision of fire detection and fire fighting equipment in buildings can be most conveniently considered under three heads:

1. Systems for detecting and giving warning of fire.
2. Extinguishing equipment for dealing with fires at their inception, including automatic equipment and manually operated appliances capable of being used by occupants.
3. Means to assist fire services in dealing with fires.

Note.—The term "fire services" refers mainly to a public fire brigade but in relation to some extensive or remote buildings may also refer to a "private" or "industrial" fire brigade consisting of one or more trained persons on the staff of the occupier.

SYSTEMS FOR DETECTING AND GIVING WARNING OF FIRE

11. An essential in reducing loss of life and property by fire is early discovery and warning of the outbreak. Fires are usually detected by direct personal observation, the discoverer warning occupants of the buildings to enable them to escape and calling the fire service (or other available assistance) by telephone or street fire alarm, or by delivering a message to the fire station. Personal observation, although satisfactory enough during day-time when most premises are occupied, is less so by night when buildings may be unoccupied or the occupants asleep. Detection and alarm would then be dependent on casual observation by passers-by or by the police. This disadvantage might be offset to some extent if efficient patrols were made at night, but in some buildings patrols may not be sufficiently frequent to allow early detection. Whilst in day-time it might be sufficient to rely on personal detection the time required subsequently to warn all occupants of a large building might be excessive. Again, in other buildings where large numbers of people congregate, early detection is essential, as a fire may start in an unoccupied room and reach major proportions before discovery, leading to greater risk of panic when the alarm is eventually given. Detection, warning and call for assistance can be facilitated by means of fire alarm systems, installed within buildings. These systems may be actuated manually, automatically, or by a combination of both methods.

12. The value of a fire alarm system depends not only on the efficiency of the apparatus in detecting fire but also on the adequacy of the warning it gives to the occupants (in some cases they must be awakened from sleep) and on the nature of the aid it can evoke (fire fighting, rescue apparatus and personnel, water supply, etc.). Factors which affect this are:

1. Its efficiency in warning occupants of an outbreak.
2. The efficiency of the help available.
3. The distance away of external help.
4. The means of communication (automatic or non-automatic) to the public fire service and/or to essential members of the staff living near by.

SYSTEMS INTENDED PRIMARILY TO SAFEGUARD PROPERTY

13. Automatic fire alarm systems have an obvious advantage because they do not depend on the presence of personnel to operate them. They are designed to give automatically a signal of the outbreak of a fire, and then should transmit a signal to a place whence help (that of a public fire service or a private fire brigade or other staff organization) may be forthcoming.

14. Buildings may be equipped with both automatic sprinklers and automatic fire alarms. A small outbreak of fire may sometimes be detected and notified by the fire alarm early enough to enable help to be brought to the scene and to extinguish the fire with hand equipment before it reaches the stage at which the sprinkler system comes into operation; in any case an automatic fire alarm system with a brigade connection provides a means of summoning personnel to control extinguishment by the sprinklers, particularly when the premises are closed.

15. In Part I of our Report we recommended that with certain exceptions, buildings of fully protected construction which do not exceed 10,000 sq. ft. area on any one floor but exceed 250,000 cu. ft. in total cubic capacity, should be fitted

with an approved automatic fire alarm system so arranged as to give a direct call to the public fire service or other efficient brigade in the event of fire. We added that this recommendation need not apply to buildings falling within the recommended limits, if they are equipped with an automatic sprinker installation such as is approved by the Fire Offices' Committee.

16. In addition to their function of extinguishing a fire, sprinkler systems are designed also to give an alarm, usually at one of the entrances to the building, and this alarm is sometimes connected electrically to a point from which help can be summoned. It is at present unusual for this point to be a public fire service station, whereas the practice of connecting automatic fire alarm systems to public fire stations is well established.

17. Other forms of automatic extinguishing apparatus are sometimes linked with an automatic alarm. Thus when a carbon dioxide extinguishing system is installed to protect a chamber or duct, it is sometimes arranged that the automatic operation of the system will first sound an alarm to warn any persons involved, then close all doors and other openings and shut off ventilating fans, so that the gas may fill the compartment so protected.

SYSTEMS INTENDED PRIMARILY TO SAFEGUARD LIFE

18. In Part I we were mainly considering the protection of the building and contents against fire; where the safety of the occupants is concerned further considerations apply. In Part III we deal with the provision of structural means of escape for the occupants. To ensure that the occupants may take full advantage of the means of escape provided, it is necessary, in buildings used by numbers of persons, to consider whether some means of giving warning of an outbreak of fire shall be provided. The fact that automatic apparatus does not depend on the presence of personnel to operate it is not necessarily an advantage over manual systems in buildings occupied or used by numbers of persons, and it may well be that in such cases manual apparatus will be actuated more quickly than is possible with automatic alarms.

19. Manual alarm systems range from a hand bell (which may be quite adequate, for example, in a small day school), triangles or sounders, to an electrical system of "break glass release" call points. The last may be arranged to awaken the occupants of the whole or part of a building, to indicate the location of the call and to summon the supervisory and other necessary staff, to call the fire service direct, or to give warning at a point from which the fire service may be called by the exchange telephone or by direct fire telephone. It is essential that the noise of the alarm be distinctive. Thus if a hand bell is used for other purposes it must not be used as a fire alarm. A further point, which it might seem superfluous to mention, is that the noise created by the operation of any one device should be sufficiently loud to be heard in all parts of the building. Such aural alarm systems are generally suitable, but in special cases, *e.g.* homes for deaf persons, it may be necessary to give consideration to visual warning systems, in addition to an efficient staff warning. These are of course special cases, and each requires individual consideration.

20. In determining the functions to be performed by any manual system in places of entertainment and assembly, large retail shops, certain types of hospital, and buildings where there are young children, it is necessary to consider whether, in order to lessen the risk of panic or of unnecessary disturbance, the alarm signal

should be confined to the staff only, who should be sufficient in number, and trained to conduct the other occupants expeditiously to safety. This method is normally adopted in cinemas, theatres and other places of assembly. In deciding whether the system should be linked direct with the fire service, consideration should be given to the fact that a false alarm may result in the unnecessary attendance of fire engines, with consequent risk of panic, *e.g.* in mental hospitals and places of entertainment. Conversely if the system is not linked direct with the fire service, it is necessary to consider whether the arrangements for manning the telephone while the premises are occupied, *e.g.* while a theatre audience is present, are such that they are not likely to fail in the event of fire.

21. It is convenient to deal first with those occupancies which involve a sleeping risk; flats, hotels, hospitals, etc. Although it is thought that the expenditure at present involved for installing alarm systems would not be justified in ordinary dwellings nor in blocks of flats, it has become evident that it is necessary to provide alarm systems in hospitals, hotels, lodging houses, residential schools and institutions generally, particularly where persons are not ambulant or are confined, *e.g.* prisons. In places where there is someone always awake, and where the building is patrolled at intervals of, say, not less than one hour throughout the night, a manual system may serve the purpose. It is, however, a wise precaution to install an automatic system in addition to the manual system in those parts of the building which are rarely visited by the staff, particularly during the night. There is some difficulty in laying down the limits of size of building at which an alarm system becomes necessary, as so much depends on the system of management and supervision and the physical characteristics of the occupants. For instance, a greater degree of precaution is necessary in a home for infants or invalids than in a hostel for able-bodied adults. It is suggested that consideration should be given to the provision of an alarm system in hotels, lodging houses, hospitals, schools and similar institutions where there is sleeping accommodation for more than 20 persons.

22. In those occupancies which do not involve a sleeping risk but involve large numbers of people, such as places of entertainment, cinematograph studios, exhibitions, large factories, offices and large shops, manual warning systems are again mainly the most suitable, though with the proviso mentioned in paragraph 20 as to the form of warning in places of entertainment and large shops. We do not consider alarm systems essential in purely office buildings though much depends on circumstances. The position with regard to factories is laid down in the Factories Act, Section 36 (7) which states:

> "Where in any factory more than twenty persons are employed in the same building, or explosive or highly inflammable materials are stored or used in any building in which persons are employed, effective provision shall be made for giving warning in case of fire."

In other cases consideration should be given to the installation of a fire alarm system, *e.g.*:

1. When in a single-storey building more than 100 persons are to be accommodated;
2. Where more than 60 persons are to be accommodated on any floor above or below the ground level;
3. In buildings not covered by the Factories Act, Section 36 (7), in which an abnormal risk arises. The number of persons is not then a factor.

EXTINGUISHING EQUIPMENT FOR DEALING WITH FIRES AT THEIR INCEPTION

23. The means which may be taken within buildings to combat outbreaks of fire immediately upon discovery in their early stages can be considered conveniently under two headings, *viz*:

(*a*) Automatic equipment.

(*b*) Manually operated appliances capable of being used by the occupants.

A fundamental difference between automatic equipment and manual appliances is that whilst the former, when properly maintained, are ready for action at all times of the day and night, the latter depend on the presence of persons capable of operating them. The automatic systems, on these grounds alone, must be regarded as the more efficient, but they have several other advantages, for example, the ability to operate in dense smoke, assured discovery and immediate alarm of fire. However, in buildings where automatic systems are adopted, some manually operated fire extinguishing appliances will still be warranted, because there is a possibility, when premises are occupied, that damage may be reduced if fire can be put out by hand-operated appliances before the automatic system functions. It is advisable, furthermore, to have a standby in case the automatic equipment is temporarily out of order or under repair.

24. There are two main types of automatic equipment; first, that designed to extinguish or hold in check fires in the buildings in which a fire has started, chief of which is the automatic sprinkler installation; and second, that designed to minimize risk of fire entering a building from an adjacent fire, *i.e.* the automatic drencher system. General details of the design and installation of these automatic systems fall outside the scope of this Report but reference may be made to the *Rules* of the Fire Offices' Committee for further particulars.

AUTOMATIC EQUIPMENT

AUTOMATIC EQUIPMENT FOR EXTINGUISHING FIRE

25. We consider that sprinkler systems, which automatically discharge water direct on to the seat of a fire, are the most efficient means of dealing with the early stages of fire in ordinary combustible materials. Experience has shown that it is essential to protect all parts of a building forming one fire risk, and not only those portions in which it is thought that a fire is most likely to occur. When a building is divided into separate risks (see Part I) each part may be considered separately and complete protection may not be necessary.

In dealing with the limitation and size of buildings in Part I we were obliged to consider the effect of the installation of sprinkler systems in the buildings. In Tables 7 and 8 of Part I and in paragraph 125 with regard to sub-basements, we indicated the maximum sizes to which we considered buildings of the various types of construction and occupancy should be erected without an approved sprinkler installation, and provided for increased sizes where sprinklers were installed. Though we have thus made recommendations for the size of the buildings for which we think sprinklers are essential from the standpoint of spread of fire alone, we are of opinion that owners would be well advised to consider the installation of sprinklers in all buildings or parts of buildings other than those with low normal fire load, even though the building is below the size recommended. Naturally their installation involves additional cost, and owners will wish to consider whether this is justified.

26. The only other point to which we need draw attention is the question of water supplies for sprinklers. No other supply for the building should be taken off the sprinkler branch. Experience has shown that if internal fire hydrants are connected to the sprinkler branch, the use of the hydrants during a fire seriously depletes the water supply to the sprinklers.

27. For dealing with fires in buildings or parts of buildings where considerable quantities of inflammable liquid are present, *e.g.* paint and varnish works, oil stores, petrol stores, oil-fuelled boiler houses, transformer rooms and oil-filled switch gear in connection with the supply of electricity, water as applied from ordinary sprinkler systems is not a suitable fire extinguishing agent. There are various methods which may be adopted accordingly to circumstances. A development of the normal sprinkler system in which the water is applied at high pressure in a fine spray is effective for some inflammable liquids. In other automatic systems materials other than water are used. These include automatic foam installations which produce and project foam over the surface of the burning liquid, but this type of equipment has not yet been fully developed for automatic working, though some successful systems have been installed. The second main type of installation using extinguishing agents other than water includes those which produce a concentration of gas around the fire which must be sufficient to reduce the concentration of oxygen to the extinction limit. Whilst effective in dealing with fires in small enclosed chambers, they are otherwise limited in effectiveness because the quantities available are usually limited and the gas is rapidly dispersed. They have, moreover, little cooling effect—a factor of greatest significance. The toxicity of some of these agents and of their products of combustion must also be borne in mind.

Parts of sprinklered buildings containing inflammable materials for which normal sprinklers are not suitable, and parts of unsprinklered buildings which may be considered of special hazard on the same account, should where practicable be completely separated from the remainder of the building by construction of the appropriate grade of fire resistance, and protected by the most suitable of the above methods.

28. Under this heading mention may also be made of so-called "deluge systems" which operate on the same principle as the normal automatic sprinkler, but provide a curtain of water within a building where a structural fire resisting separation is impracticable. They are used in special circumstances only and each case must be considered on its merits.

AUTOMATIC EQUIPMENT FOR RESTRICTING SPREAD OF FIRE

29. Automatic drencher systems are similar to sprinkler systems except that they are specifically designed to prevent the entry of fire into buildings by spraying water over window openings, roofs, etc. As in the case of sprinklers, we considered the protection afforded by drenchers in arriving at the recommendations in paragraphs 244 to 250 in Part I for the protection of openings in the external walls of buildings. It is necessary that the water supplies for a drencher system should be governed by the same principles as those we have indicated in relation to sprinkler systems. The drencher supply should also be separate from the sprinkler supply.

MANUALLY OPERATED APPLIANCES

30. Manually operated appliances intended for use by any active person on the spot, though valuable, are only designed for immediate use on a small fire, and should not be regarded as sufficient reason for not calling for assistance nor for the omission of any automatic extinguishing apparatus or any apparatus to be used by firemen in controlling major fires.

MANUAL APPLIANCES USING WATER

31. Water is by far the most effective extinguishing agent for use in hand appliances for fires in ordinary combustibles, but it is not suitable for fires involving oils, fats and inflammable liquids not miscible with water, nor for fires in buildings containing materials which may react chemically with water, *e.g.* sodium, calcium carbide. When it is used for fires in electrical wiring or apparatus (see paragraph 33) it is essential to switch off the current first. All buildings except small dwellings should have, for use by the occupants, some form of hand fire extinguishing appliance such as fire extinguishers, hand pumps, small hydrants or hose reels within the premises, or close at hand in the case of ancillary buildings. For small dwelling houses we regard the protection which can be provided by the domestic water supply as sufficient.

32. Hand appliances suitable for use by untrained persons should be located so that a person will not have to travel more than 50 ft. from any point in the building to reach the nearest appliance; at least two appliances should be located on each storey and further appliances should be provided so that there is, over all, one appliance for each 2250 sq. ft. of floor area on each storey. An "appliance" for this purpose is considered to be a standard 2 gallon extinguisher, three buckets of water, or two buckets of water and a stirrup pump. Alternatively small rubber hose reels ($\frac{3}{4}$ in. internal diameter with a $\frac{3}{16}$ in. nozzle) or small hydrant outlets for use with $1\frac{1}{4}$ in. or $1\frac{1}{2}$ in. canvas hose with $\frac{3}{16}$ or $\frac{1}{4}$ in. nozzle, both not exceeding 60 ft. in length, may be provided on each storey at the rate of one reel or outlet to each 4500 sq. ft. of floor area, subject however, to the condition that every part of the storey protected can be properly covered by the jet. Where wet rising mains are provided for the use of firemen, it is possible to adapt them to serve as supply mains for hose reels or canvas hoses. The minimum running pressure at the highest nozzle should be 12 lb. per sq. in. Where apparatus involving the use of small rubber or canvas hose is provided for use by occupants, one piece of apparatus should be near each exit or staircase landing on each floor. Care should be taken to place the apparatus in such a position that when in use it does not impede the means of escape or the closing of doors protecting staircases. Some obstruction is sometimes unavoidable but it should be reduced to the minimum.

SPECIAL PURPOSE MANUAL APPLIANCES

33. For immediate attack on small fires in inflammable liquids not readily miscible with water the best agent is foam. Carbon dioxide extinguishers and certain inert powders are rapid to use but are effective only against fires in small quantities of inflammable liquids, small calcium carbide and phosphorous fires. Carbon dioxide is also useful against small fires involving electrical wiring.

34. Where inflammable liquids immiscible with water are used or stored, at least one foam type extinguisher should be located so that a person will not have to travel more than 50 ft. from the place where the liquid is used or stored to reach the nearest appliance. One foam appliance should be installed within easy reach of each container or apparatus containing inflammable liquid. Any hand appliance specially installed for the protection of inflammable liquid, etc., should be additional to those installed for ordinary combustible materials. Arrangements should be made to avoid, if possible, the accidental use of an extinguisher projecting water on to a fire in inflammable liquids and to ensure that foam only is used. It cannot be too strongly emphasized that the limitations of appliances for manual operation by any active person on the spot apply particularly to fires in inflammable liquids.

MEANS TO ASSIST FIRE SERVICES

35. The most effective means of attacking a fire is to enter the building and attack the fire from as short a range as possible. Hose jets from the street are sometimes the only feasible means of attack, but they are mainly of value in meeting the risk of exposure fires. The work of the fire services may be greatly assisted by the incorporation in and around buildings of certain facilities and equipment. These are:

1. Access facilities for firemen in and around buildings.
2. Means for ventilating fire.
3. Means to speed the actual extinguishing operations.

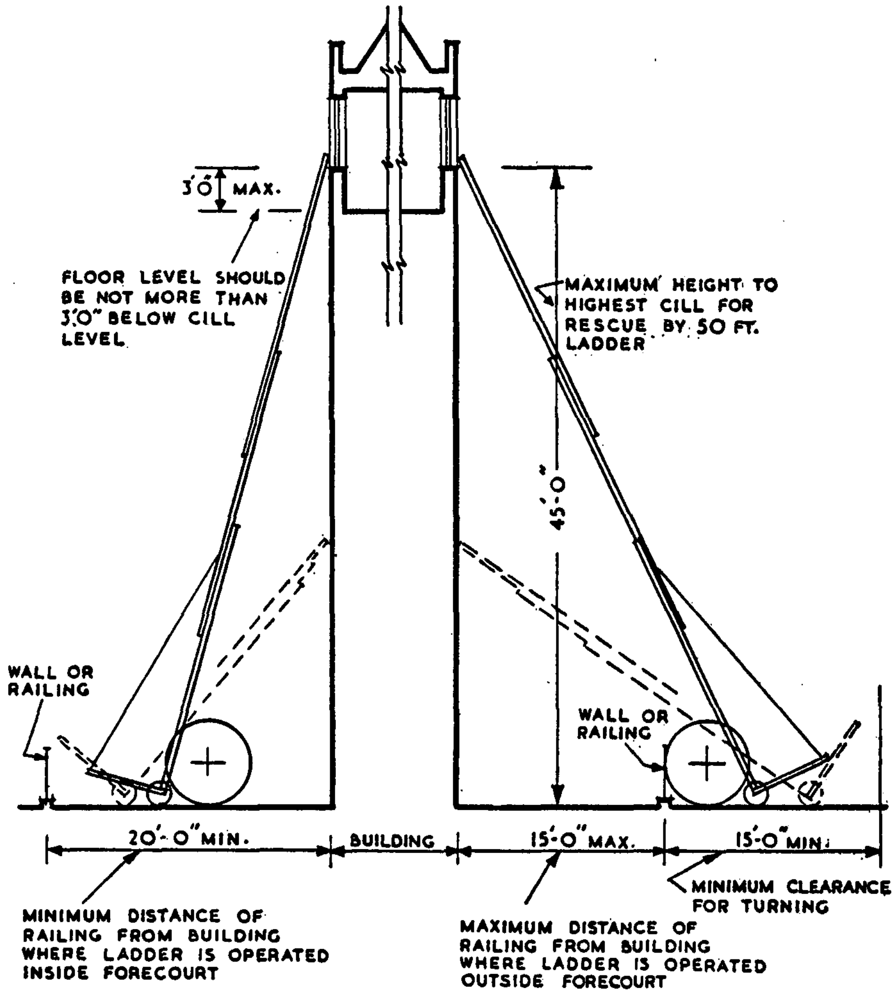
ACCESS FACILITIES

36. Access facilities both around and to the inside of a building play an important part in the success or failure of fire fighting operations. We had occasion, when considering the limitation of size of buildings in Part I, to recommend a minimum standard of accessibility to the buildings as a whole from streets or equivalent open spaces around buildings, and referred also to the need for providing terraces in high buildings by setting back the external walls at each floor level above a height of 100 ft. So far as entry into the building is concerned the doorways normally provided should be adequate in most circumstances, but when those entrances are blocked it is the fireman's duty to gain entry by any available means. Whilst we do not feel that further specific recommendations are justified, any additional measures which can be taken to assist access with due regard to cost and burglary risk, should be adopted, *e.g.* staircases, wherever possible, should be adjacent to external walls.

37. Access to the roof from inside the building is now usual in most large buildings and this again should be considered as a means of entry for the fireman and should be provided for this purpose; obvious advantage accrues from a flat roof. The installation of fire towers in buildings has also to be considered from this standpoint. They form a valuable means of access for firemen, but on the assumption that means of escape is provided on the basis we have recommended in Part III, we do not consider additional access for firemen by means of fire towers is strictly necessary, provided that staircases are adjacent to external walls and are furnished with windows so that the staircase can be ventilated. The question of the provision of access for firemen by means of fire towers, however, becomes important when buildings appreciably over 100 ft. high are considered. Very few buildings of such heights have been built in this country although they are common in the United States. We have not thought it necessary to enter into a detailed study of this matter, for whilst the general principle of ensuring properly protected access still holds, the application to a particular building will need individual consideration in each case.

38. In Part I we recommended smoke vents from certain basements and sub-basements. Iron ladders fixed in these vents provide a valuable means of access for the firemen and should be included whenever possible. Again, in dealing with the provision of structural means of escape in Part III we recommend that single staircase buildings of limited size should be allowed in certain cases in areas where prompt attendance of the fire service with suitable rescue appliances, *i.e.* the 50 ft. wheeled escape, can be expected. The windows of all rooms to which this condition applies must therefore be readily accessible for firemen using the 50 ft. escape, and access must not be obstructed by railings, trees, shrubs, narrow gateways, etc.

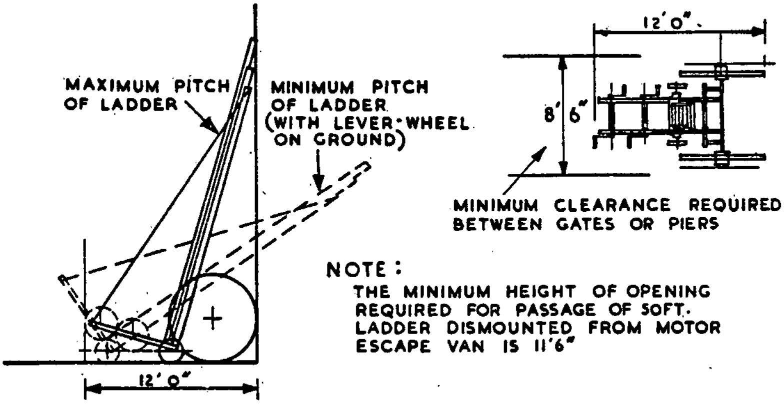
We indicate in Figs. 1 and 2 the minimum distance which should be allowed for access of the escape ladder together with other relevant particulars of the 50 ft. escape. In districts where a 100 ft. turntable ladder is available it is desirable that there should be a road, capable of carrying the weight of the ladder, at a suitable distance away from at least one side of all buildings over 42 ft. high to the topmost floor. Particulars of the 100 ft. ladder are given in Fig. 3.



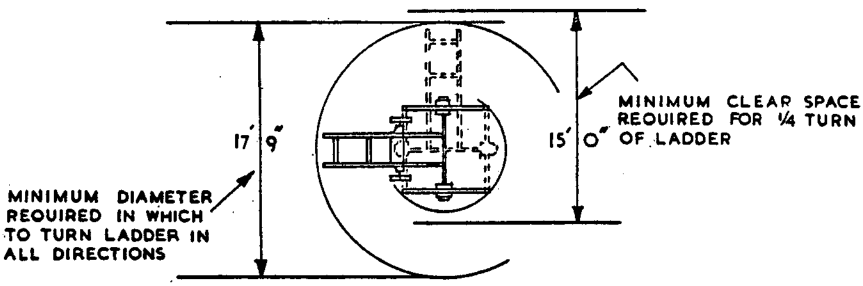
There should be no forecourt wall or railing between the distances of 15′ 0″ and 20′ 0″ from building. Entrance gates for access of ladder should be provided in the forecourt railing if it is 20′ 0″ or more from the building. Kerbs under gates should not be more than 6″ high.

FIG. 1

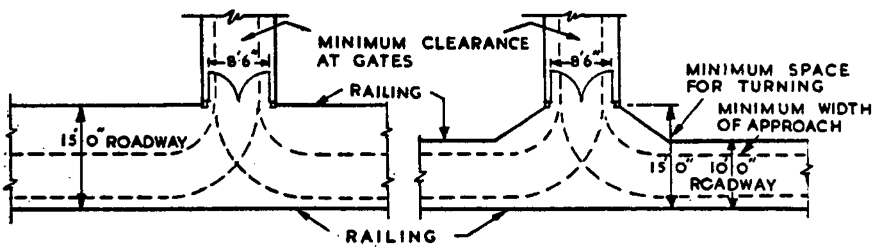
RESCUE FROM UPPER FLOORS BY 50 FT. ESCAPE LADDER—DIAGRAM ILLUSTRATING MAXIMUM CILL HEIGHT AND DISTANCES OF FORECOURT RAILING FROM BUILDING



MAXIMUM OVERALL DIMENSIONS OF LADDER, ETC.



MINIMUM TURNING SPACE FOR LADDER



MINIMUM DIMENSIONS OF APPROACH ROADWAYS

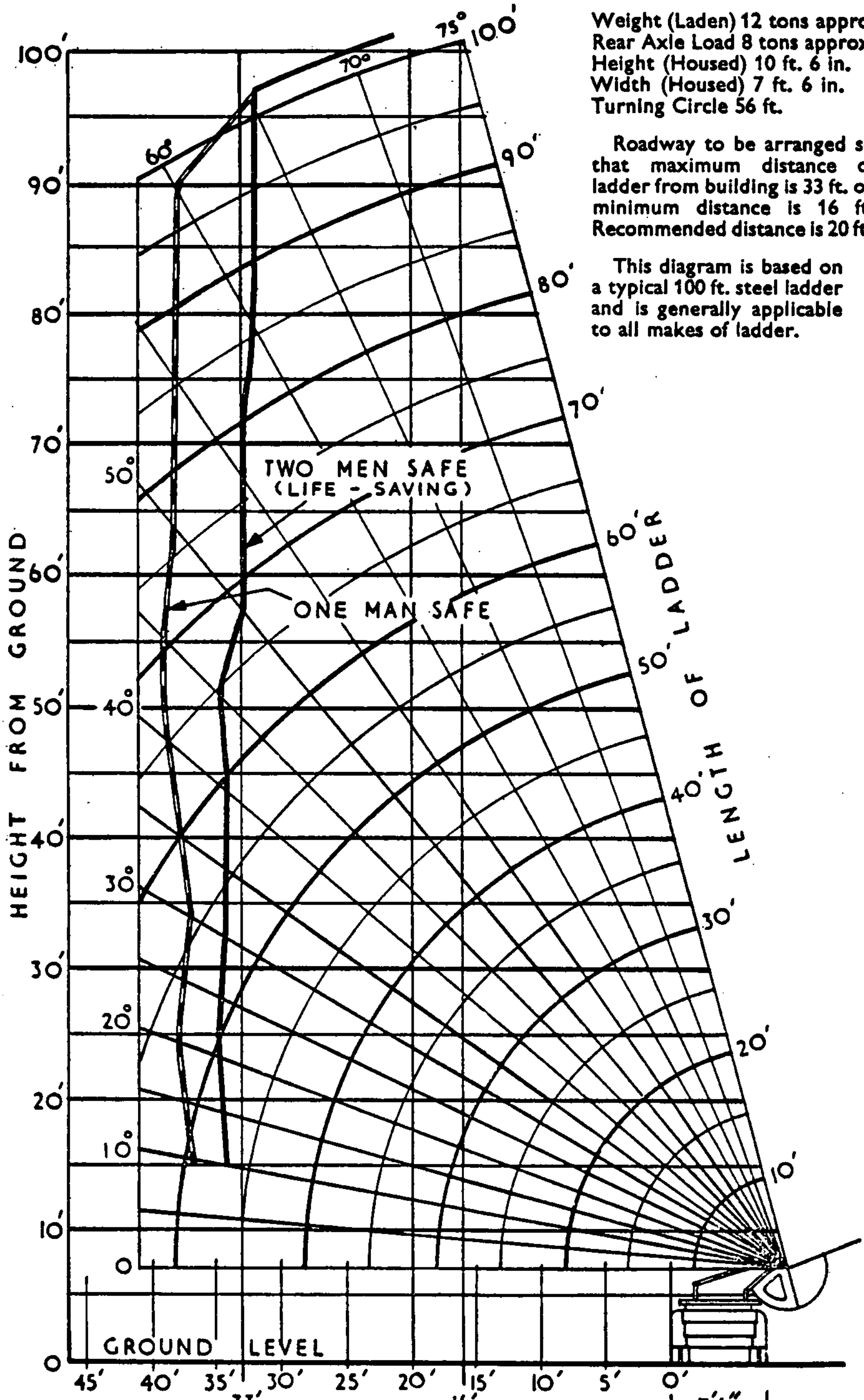
FIG. 2

50 FT. ESCAPE LADDER—VARIOUS PARTICULARS

Weight (Laden) 12 tons approx.
Rear Axle Load 8 tons approx.
Height (Housed) 10 ft. 6 in.
Width (Housed) 7 ft. 6 in.
Turning Circle 56 ft.

Roadway to be arranged so that maximum distance of ladder from building is 33 ft. or minimum distance is 16 ft. Recommended distance is 20 ft.

This diagram is based on a typical 100 ft. steel ladder and is generally applicable to all makes of ladder.



SAFE WORKING ANGLES AND EXTENSIONS FOR LADDER DIRECTED ACROSS CHASSIS

FIG. 3

100 FT. TURNTABLE LADDER—VARIOUS PARTICULARS

VENTILATION OF FIRE

39. The proper ventilation of smoke and hot gases from a burning building is a problem which calls for expert judgment on the part of the fireman. Its application at the right time may considerably reduce the spread of fire by preventing "mushrooming" of the smoke and hot gases into other parts of the building and by facilitating the movement of firemen. Ventilating is usually achieved through doors, windows, roof lights, etc., but it is often desirable to incorporate in the building structure special means of ventilation which will function directly a fire occurs, or which may be opened by the fireman. In this connection we have already, in Part I, recommended that stairway, lift and other shafts which continue to the top of a building, should be provided with smoke vents above the roof level, and again, that basement and sub-basements without natural means of ventilation should each be provided with special smoke extract ducts.

40. We might mention also the recommendation for providing means of ventilating fires occurring on theatre stages by means of light glazing in part of the roof (Home Office *Manual for Safety Requirements in Theatres, etc.*). We consider that further specific recommendations cannot be justified, but we do suggest that it would be advantageous to provide similar means for facilitating the ventilation of fire wherever it is found practicable. In situations such as the roofs of spraying rooms, film working rooms, and places where inflammable liquids are used, the provision of roof lanterns with light glazed openings which will fracture readily in the event of internal fire, can be of great value. Due regard must be paid to exposure hazard where there are adjacent buildings.

41. We have already referred (paragraph 37) to the desirability of providing access for firemen at the head of all staircases which reach to the roof and to the need for staircases which provide access for the fire fighters to be adjacent to the external walls. Both these provisions would greatly facilitate the ventilation of a building in the event of a fire. Although with fire resisting construction there is reasonable prospect of a fire being confined to one compartment, there is still the risk, owing to the relatively "gas tight" condition of modern buildings, of the stairs and other vertical shafts becoming smoke-logged with gases which escape through the interstices around the doors to the compartments. If these heated gases are not released from staircases there is risk that they will eventually penetrate to other compartments and thus spread the fire. The suggested provisions should make it possible for firemen to open or break windows on staircases, and to open doors at the head of staircases, and thus release the smoke and hot gases.

MEANS TO SPEED EXTINGUISHING OPERATIONS

42. The recommendations in Part I as to size of buildings were made with due consideration for the fire fighting aspect on the basis that the less the degree of fire resistance of the structure in relation to its fire load the less would be the time available to prevent a serious fire from spreading from the compartment in which it started to other parts of the building. It follows that all reasonable precautions should be taken to enable the fire service to expedite the extinguishing operations. In this connection the incorporation of mains fitted with hydrants in the building reduces the necessity for laying out lines of hose up staircases or over long distances—a cumbersome and slow process—and thus permits water to be applied more quickly to the seat of fire.

43. In Part I we recommended mains with indoor hydrant outlets in buildings or divisions which exceed 10,000 square feet in area, and where any portion is more than 100 feet from the street. We also indicated that special fire fighting facilities, for which we had chiefly in mind rising mains, were an essential feature

for multi-storey buildings exceeding 100 feet in height. Rising mains should also be installed in buildings containing abnormal occupancies where the time factor may be of even greater importance than in normal occupancies.

44. Rising mains should be located in positions readily accessible to firemen, *i.e.* within staircase enclosures. Outlets should be provided at each floor level and at the roof on the basis of one outlet for every 10,000 sq. ft. of floor area, providing that all parts are within reach of a $\frac{3}{4}$ in. jet at a suitable pressure from not more than 100 ft. of hose, including parts which are enclosed by partitions. Water supplies for indoor hydrant systems should be arranged so that they cannot interfere with the supply to any sprinkler or drencher system installed in the building. In buildings not exceeding 100 ft. in height where there is reasonable certainty of a fire being attended by at least two major pumping appliances of the public fire service within 5 minutes of the receipt of a call, the rising main need not be connected to the public water supply, but instead may be arranged "as a dry rising main," *i.e.* for the fire service to pump water into it from the street mains or other source of water supply.

45. It will be realized that attack by the fire service with their mobile appliances working from the street level becomes very difficult in buildings greatly exceeding 100 ft. in height and that the fire extinguishing apparatus installed in the building must be adequate to deal with any fire likely to occur therein. Special independent water supplies with fixed pumps capable of operating at all times, even under emergency conditions, *e.g.* during a failure of the electrical supply, will be necessary. No established practice can be laid down in view of the very few buildings of this height in this country, but if the position should change it would be desirable to study the methods adopted in the U.S.A. in respect of both fire extinguishing apparatus and access for fire attack.

46. The main types of apparatus suitable for installation in buildings containing inflammable liquids in bulk are systems for the production of foam. Where large quantities of inflammable liquids are involved piping and connections should be permanently attached to the liquid containers, so that in the event of fire foam can be directly applied to the surface of the liquid. Unless readily available in the public fire service, foam producing equipment should be provided and ample supplies of material required to produce foam should be available on the premises. In some cases where the fire service is equipped with adequate foam producing apparatus, but where the inflammable liquids are in buildings or parts of buildings not readily accessible to the fire service, dry mains should be provided—accessibly located on the street frontage so that the fire service can pump foam directly on to the surface of the liquid and any spillage area.

PART III. PRECAUTIONS RELATING TO PERSONAL SAFETY

GENERAL

47. In Part I of our Report we considered the structural fire precautions which are desirable in new buildings to minimize the risk of loss of the buildings and their contents, and also to reduce the risk of fire spread from one building to another. In this Part of our Report we shall consider the additional precautions which are thought necessary to ensure the safety of occupants in case of fire.

48. As an approach to this question of personal safety it is instructive to follow the course of events from the start of a fire, by considering, for example, the development and effects of a fire starting in an occupied room. The danger to the occupants depends on the rate at which fire spreads in the contents of the room, and also on the linings of walls and ceilings. There is also a danger from panic in rooms where a considerable number of people are gathered. Of these factors, the surface finishes are a constructional matter and the nature of the contents and the population density depend on the occupancy. Although the danger can be minimized by giving attention to structural matters such as surface finishes, the provision of adequate exit facilities is an even more important contribution to personal safety.

49. If the fire spreads beyond the room in which it starts, the danger to people in other parts of the building depends, in the first place, on the ease with which smoke and hot gases can spread through the building. It is generally recognized that this is the major factor causing danger to life in building fires, as the majority of fire fatalities are due to asphyxiation and not to burning. Personal safety can again only be assured by the provision of adequate means of escape, properly designed and constructed in order to prevent spread of fire and smoke along them and to give safe access to the ground for all the occupants of a building. It has been found that quite small quantities of smoke may deter people from using escape routes, either through physical discomfort or through panic. It is therefore important to provide such barriers as self-closing doors where necessary to prevent the spread of smoke or hot gases from one part of a building to another.

50. In the final stage of fire spread, life may be endangered by penetration of flame or heat through walls, floors or partitions, or by structural collapse. It should be noted that, even where structural elements such as floors do not burn or collapse, the passage of heat through them may create an air temperature which is dangerous to life. This fact is specially important in buildings where the occupants may not get an immediate warning of fire, or may be asleep or suffer from physical disabilities.

51. It is apparent therefore that the problem has two distinct though complementary aspects, namely, attention to structural precautions, and provision of means of escape. We have accordingly divided this Part of the Report into two Sections:

Section 1. Construction in Relation to Personal Safety.

Section 2. Means of Escape.

52. In considering these two aspects of the problem it will be found that the necessary precautions will be closely related to the occupancy characteristics of buildings. The differences between different occupancies in planning, population

density and conditions of use are considerable, and it is desirable in the first instance to evolve an occupancy grouping as a basis for recommendations. Apart from grading occupancies according to their characteristics, it is necessary also to give detailed consideration to the subject of population densities in different occupancies, and to make some recommendations so that the total number of persons which can reasonably be expected in any building can be calculated. These matters will therefore be dealt with as a preliminary to the two main Sections.

OCCUPANCY CHARACTERISTICS AND GRADING

53. In Part I (paragraph 27) we indicated that it would be necessary to approach the question of grading of occupancies in two stages:

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

The first was dealt with in Part I on the basis of "fire load" and we have now to consider the second.

FUNDAMENTAL CHARACTERISTICS

54. Two distinct types of characteristics are apparent:

1. Population characteristics, *i.e.* the number of occupants, their distribution in the building, their physical condition and the way in which they can be expected to react in any emergency. The last two characteristics depend on such factors as age, discipline (by fire drill, for example), and whether they are asleep or alert.
2. The use to which the building is put, *i.e.* the nature of the contents of the building, including furnishings, goods stored or displayed and processes carried on.

55. In considering these characteristics in relation to particular occupancies it is convenient to separate the occupancies into groups.

PRIMARY GROUPING BASED ON POPULATION CHARACTERISTICS

56. The clearest grouping results from a division according to population characteristics, and on this basis the following primary grouping is suggested.

Group A. *Assembly Buildings*, *e.g.* public halls, dance halls, club rooms, restaurants and similar buildings. The general characteristics of this type of occupancy are high population density and large undivided floor areas, so that a considerable number of people get simultaneous warning of fire. These people may vary widely in age and physical condition, and are not, in general, subject to strict control under fire conditions. In these circumstances the possibility of panic is a major consideration.

Group B. *Trade*, *Commercial and Industrial Buildings*, *e.g.* offices, shops, warehouses and factories. In these occupancies the people are generally alert and able-bodied and they are normally spread over considerable floor areas, many of them remote from the floor and place where fire originates. In these circumstances the possibility of panic is reduced, especially in cases where good discipline can be expected on account of such precautions as fire drills. Discipline of this kind cannot, of course, be expected in such places as shops, where the public is admitted.

Group C. *Residential and Institutional Buildings*, in which there is a "sleeping" risk. These include flats, hotels, boarding schools, hospitals, homes for old people and for the blind, jails and asylums. It cannot too strongly be emphasized that the outstanding characteristic of this type of occupancy is the risk which may arise from the occupants being asleep. This will in some occupancies be accentuated by the presence of invalids, children, or infirm and old people. These sleeping and infirmity risks are very important because they may cause a delay in evacuation until considerable fire spread has occurred, and so greatly increase the personal hazard to the people involved. In institutional buildings there is also the factor that the occupants are largely dependent on trained staff, a factor which is most important in the case of places of detention such as jails and asylums.

PRIMARY GROUPING BASED ON USE

57. It will be seen that the foregoing grouping according to population characteristics is, at the same time, quite a natural division according to use. There are, however, one or two occupancies which seem to belong to one main group according to use, and to another group according to population characteristics. For example, in department stores, which would seem to belong to Group B, the population density and large undivided floor areas frequently produce conditions identical with those of an assembly occupancy, especially as regards danger of panic. This applies particularly to floors used for bargain departments or for the sale and display of low-priced articles which attract a casual, sight-seeing interest on the part of the public. Assembly conditions also exist on floor areas used as restaurants or for such purposes as exhibitions. It is desirable that the recommendations for assembly buildings should apply to the parts of department stores mentioned here. Another example of a border-line grouping is that of non-residential schools. These would most naturally be classed as assembly occupancies, yet the population is normally split up into classroom units, so that true assembly conditions only exist when the whole school is gathered together for such a purpose as a concert. With an efficient warning system, however, there may be practically simultaneous discharge from the various classrooms, giving a fair approximation to assembly conditions.

SUBDIVISION ACCORDING TO POPULATION CHARACTERISTICS

58. Considering each of the suggested main occupancy groups from the point of view of population characteristics, certain subdivisions become apparent. These are given below.

Group A. ASSEMBLY BUILDINGS

A distinction in population density has to be made between places with a closely seated audience, such as concert halls, and other occupancies such as dance halls and restaurants which do not have fixed seating. Among those occupancies where fixed seating is used, theatres and cinemas may be considered to constitute a separate class on account of specialized planning. Besides the occupancies mentioned above, there are many minor assembly buildings such as club rooms and buildings which have a number of small assembly rooms. Some of the latter can scarcely be classed as assembly occupancies from the point of view of population characteristics, but may be included here for convenience. Mention must also be made of assembly buildings used for more than one purpose, *e.g.* public halls used for dancing or concerts, and restaurants used for dancing. In such cases the occupancy should be grouped according to the use in which the personal hazard is greatest.

The following subdivision of Group A is suggested.

1. Theatres and cinemas.
2. Other halls with a closely seated audience.
3. Exhibition halls.
4. Dance halls.
5. Restaurants.
6. Club rooms and similar minor assembly occupancies.
7. Non-residential schools.
8. Department stores—ground floor, sales basements, and any upper floor used for bazaars or special sales displays.

Group B. TRADE, COMMERCIAL AND INDUSTRIAL BUILDINGS.

In this group a distinction has first to be drawn between buildings open to the public, *e.g.* retail shops and department stores, and buildings not open to the public, *e.g.* warehouses, factories and office buildings. The former are liable, on occasions such as sales days, to be frequented by considerable numbers of people who would not be subject to the discipline which could be expected in factories and warehouses. Of the buildings not open to the public, offices are a sharply defined category in layout and general fire risk, while the distinction between warehouses and the compact type of factory building with several storeys is mainly a matter of population density. On the other hand, the modern type of single-storey factory with a large floor area presents substantially different conditions, and, to take an extreme case, in many large engineering workshops, the question of personal safety from fire does not seriously arise.

The following subdivision of Group B is suggested:

1. Retail shops.
2. Department stores—upper floors (except as Group A (8) above).
3. Offices.
4. Warehouses and wholesale stores.
5. Factories—except large single-storey buildings.
6. Large-area single-storey factories.

Group C. RESIDENTIAL AND INSTITUTIONAL BUILDINGS

The subdivision of this group requires a distinction to be made between purely residential buildings and institutional buildings in which the occupants are, to a greater or less extent, dependent on trained staff. Among the residential buildings further subdivision is mainly a matter of population density. In the case of institutional occupancies, places of detention such as jails and asylums constitute a well marked sub-group and require very special attention. The following subdivision is suggested:

1. Flats, maisonettes.
2. Hotels, boarding houses, hostels.
3. Residential schools, institutions.
4. Hospitals, nursing homes, homes for old people.
5. Places of detention, jails, asylums.

SUBDIVISION ACCORDING TO USE

59. It is now necessary to consider the effect of the contents of a building on the occupancy grouping. The amount of combustible material, measured by the fire load, is not generally of primary concern from the point of view of safety of life, as the fire severity built up during the short time interval required for evacuation need not be greater in buildings of high fire load than in buildings of low fire load. The rate of fire spread is a more important factor. In Part I of the Report a distinction was drawn between materials and processes giving a normal fire risk and those giving an abnormal fire risk. This distinction can usefully be applied to give the necessary subdivision of occupancies according to contents.

60. Considering groups A and C it will be seen that, within each group, the contents of all buildings will be of a fairly well-defined and standardized type, coming within the low normal fire load category. In residential buildings, for example, the contents will be ordinary domestic furniture, and the fire hazard involved will not vary substantially from one building to another.

61. In Group B occupancies there is a considerable variation in the contents of different buildings of the same type. In only one of these, *i.e.* offices, are the contents substantially similar. Warehouses, shops and factories all show a wide variation according to the quantity and nature of the goods involved or the processes carried on. In warehouse and factory buildings it is particularly necessary to draw a distinction according to contents, and in these cases sub-division into the two types, normal and abnormal hazard, is required, as in Part I.

Summary of Occupancy Grading

62. We give below a complete list of the occupancy groups with their subdivisions.

Group A. ASSEMBLY BUILDINGS

1. Theatres and cinemas.
2. Other halls with a closely seated audience.
3. Exhibition halls.
4. Dance halls.
5. Restaurants.
6. Club rooms and similar minor assembly occupancies.
7. Non-residential schools.
8. Department stores—ground floor, sales basements and any upper floor used for bazaars or special sales displays.

Group B. TRADE, COMMERCIAL AND INDUSTRIAL BUILDINGS

1. Retail shops.
2. Department stores—upper floors (except as Group A (8) above).
3. Offices.
4. Warehouses and wholesale stores.
    a. Normal hazard.
    b. Abnormal hazard.
5. Factories—except large single-storey buildings.
    a. Normal hazard.
    b. Abnormal hazard.

6. Large-area single-storey factories.
   a. Normal hazard.
   b. Abnormal hazard.

Group C. RESIDENTIAL AND INSTITUTIONAL BUILDINGS

1. Flats, maisonettes.
2. Hotels, boarding houses, hostels.
3. Residential schools, institutions.
4. Hospitals, nursing homes, homes for old people.
5. Places of detention, jails, asylums.

POPULATION DENSITY

63. The maximum number of persons which can reasonably be expected in any building cannot always be determined accurately. In some occupancies planning provides accommodation for a predetermined number of people. In buildings such as theatres the number for which fixed seating is provided can be accepted as accurate for the present purpose. Other occupancies such as schools and hotels, while designed for definite numbers of people, are liable to a variation in the actual maximum number of occupants, depending on the use of the accommodation provided. Apart from such a possibility, which can often be allowed for with reasonable accuracy, the number of people in these occupancies is determined by planning considerations.

64. On the other hand, in occupancies such as offices and shops there is no direct means of assessing the number of occupants. Moreover, the conditions of use may change substantially from time to time. In such occupancies the number of occupants to be considered for escape purposes must be estimated from the floor area using a figure for floor space per person based on observation and judgment. The value of this figure for population density in occupancies where the number of people cannot be obtained directly is the problem with which we are concerned here.

65. In practice population density in these occupancies may vary considerably from one building to another of the same occupancy type. For example, a retail shop selling low-priced articles of common use would naturally be much more crowded at peak shopping periods than a shop dealing in expensive luxury goods. It is difficult, however, to make a clear-cut distinction in population density between any subdivisions of a particular occupancy type, *e.g.* between shops selling different types of goods. The advisability of making such a distinction is, in any case, doubtful, because of the possibility of change in tenancy or use. The population density figure must therefore represent a compromise giving a reasonable maximum population under average conditions.

66. The variation in population density which occurs in practice is reflected in the varying figures given in existing codes. The extent of this variation will be seen in Table I which summarizes the provisions of some representative codes. It will be noted that, in general, these codes give figures for occupancies of all types. For the practical purpose of building design and regulation we consider it unnecessary to state arbitrary figures for population density in those occupancies where the number of people in a building can be determined with reasonable accuracy from planning or licensing considerations. In the following paragraphs some data are given on which we have based recommendations for population density in occupancies where the number of people must be estimated from the floor area.

TABLE I. POPULATION DENSITIES IN EXISTING CODES

OCCUPANCY	SQUARE FEET PER PERSON				
	L.C.C.	B.I.N.C.	CANADA	NEW YORK	CALIFORNIA
Assembly Buildings					
Theatres and Cinemas			6		6 or 7 (a)
Halls with closely seated audience	5	6	6		6 or 7 (a)
Dance Halls	10	10	15	10	6
Restaurants	12	20 (b)	40	10	20
Club rooms and the like		20	15 (c)	10	
School class room floors		40	40	15 (d)	20
Department stores. Ground floor and sales basement	5 in (e) gangways	20	30		
Churches			15		6
Libraries			40	25	50
Trade, Commercial and Industrial Buildings					
Retail shops	50	75		25	
Department stores except as above		75	60		
Offices	100	75	100	100	50
Warehouses	150	300	300		100
Factories—Generally	400 c. ft. (f)	50	100	25 (g)	50 to 100
Large-area single-storey factories		200			
Residential and Institutional Buildings					
Block dwellings		140	125 (h)		125 (h)
Hotels—bedroom floors		200	125		75
Luxury flats		200			
Residential schools — bedroom floors		55			100 (j)
Hospitals		150 (k)	100		75
Jails and Asylums					75

(a) 6 for level floor, 7 for sloping floor. (b) In hotels and mansion flats. (c) 6 in any part with fixed seats. (d) In class rooms. (e) Applies to "bazaar" or "bargain" departments of retail trade premises frequented by persons in large numbers. (f) This is in accordance with the Factories Act, 1937. (g) In work rooms. (h) Apartment houses. (j) Dormitories. (k) Institutional buildings in general.

67. To avoid repetition, abbreviated titles are used throughout this Part of the Report for various existing codes and the full titles with the abbreviations used are given below:

L.C.C.—London County Council. *Means of Escape in Case of Fire : Principles for the Guidance of Applicants in the Preparation of Proposals to be submitted for the Council's Approval.* (Revised—February, 1946.)[1]

B.I.N.C.—Building Industries National Council. *Report on Means of Escape in Case of Fire.* June, 1945.

N.F.P.A.—National Fire Protection Association (U.S.A.). *Building Exits Code.* Seventh Edition, 1942.

Canada—*National Building Code* (*Canada*), 1942.

New York—*Building Code of the City of New York* (Effective January 1st, 1938).

California—*Building Code for California*, 1939.

N.B.F.U.—*Building Code recommended by the National Board of Fire Underwriters* (*New York*). Fifth Edition, 1934.

[1] This document has been further revised since our Report was prepared.

BUILDINGS WITH A CLOSELY SEATED AUDIENCE

68. There is little disagreement between existing codes with regard to the population density in this type of building. The figures given for the space occupied per person vary between 5 and 7 sq. ft. It is useful to consider these figures in relation to the seating of cinemas, which represents a modern standard of practice in this respect. Cinema seats are usually 20 in. wide and about 2 ft. 6 in. from back to back, the dimensions generally varying slightly in different parts of the auditorium. A space 2 ft. 6 in. by 1 ft. 8 in. has an area of 4·2 sq. ft. The proportion of floor space occupied by gangways is about 40 per cent. to 60 per cent. of net seating space. On this basis the equivalent space occupied per person with seats 20 in. wide and 2 ft. 6 in. from back to back would be approximately 6½ sq. ft.

69. In halls where movable seating is used, a lower standard of seating accommodation can be expected. In these, the seats do not usually have arms, as is customary in cinemas, and the width may be reduced to 18 in. Also it is possible to get the seats somewhat closer than the 2 ft. 6 in. spacing from back to back already mentioned. Allowing for an area 2 ft. 3 in. by 1 ft. 6 in. and 50 per cent. extra for gangways, the equivalent space occupied per person would be about 5 sq. ft.

70. We consider that, in assembly buildings with movable seating, population should be estimated on the basis of 5 sq. ft. per person. In buildings with fixed seating the designed seating capacity can be used, with a suitable allowance for standing room if standing is allowed.

DANCE HALLS

71. The popularity of modern dancing results in very large attendances at popular dance halls; the number present is often such that it is hardly possible for all to be on the floor at once, and conditions in respect of population density are at least comparable with those in a cinema or other closely seated audience. We consider that the densities previously adopted (Table I) may underestimate the numbers in many cases, and suggest that in future it may be necessary in some cases to adopt a figure as low as 6 sq. ft. per person. The final decision should rest with the competent authority.

RESTAURANTS

72. It is a matter of everyday experience that there is a wide variation in the space per person in restaurants of different types. This condition is reflected in existing codes, where the number of sq. ft. allowed per person varies between 10 and 40. It should be remembered that the figure depends on whether the area used for calculation includes kitchen and service space. The higher figures have probably been arrived at by including all floor areas connected with the restaurant, and the lower figures by taking account only of dining space occupied by the public. In view of the fact that population density varies widely in restaurants it is considered undesirable here to introduce a further variable by including kitchen and service space.

73. The floor space per person in restaurants and canteens is generally within the range 8 to 16 sq. ft. In very crowded restaurants the figure may be as low as 7 sq. ft., but that is exceptional. In more expensive restaurants and hotel dining rooms, on the other hand, the space per person may exceed 16 sq. ft. A typical range for the popular lunch room or cafeteria type of restaurant is 9 to 13 sq. ft.

per person. The Ministry of Education *Regulations Prescribing Standards for School Premises*, 1945, lay down a minimum figure of 9 sq. ft. per seat in dining rooms of secondary schools. In canteens attached to hostels for war workers the figure was also about 9 sq. ft. per person.

74. It is recommended that for escape purposes, the population in restaurants should be based on a figure of 10 sq. ft. per person. This figure is to be applied to the dining space occupied by the public.

OFFICES

75. The following figures are taken from the Report of the Business Buildings Committee convened by the R.I.B.A.[1]

A reasonable average of population in the "rentable" office area of office buildings designed for speculative letting can be assessed on the basis of 70 sq. ft. per person. Rentable office space may be as much as 75 per cent. of total floor area. In four London office buildings designed by one firm of architects just before the war the average was 71·5 per cent. On the basis of these figures the number of sq. ft. of gross floor area per person would be 93.

76. In the publication of the U.S. National Bureau of Standards, *Design and Construction of Building Exits*, figures are given for population density in twenty office buildings surveyed for the purposes of that Report. The figures vary from 66 sq. ft. per person to 160 sq. ft. per person, the average being about 110 sq. ft. per person. This sample is not necessarily statistically accurate. It is significant that the most densely populated building was also one of the largest, a building of seventeen storeys and 20,000 sq. ft. floor area per storey.

77. It should be noted that population figures higher than the average are likely to be reached in special instances. Some types of offices are liable to have numbers of persons calling for business purposes, *e.g.* offices of Government Departments and Local Authorities, whilst in other office buildings in single tenancy considerable numbers of employees doing routine office work may occupy large undivided floor areas. On the basis of the information in the foregoing paragraphs we consider that a population density figure of 100 sq. ft. of floor area per person should be adopted, based on gross floor area (excluding lavatories and staircases).

FACTORIES

78. The population density in factories is controlled under the Factories Act on the basis of cubic capacity of a workroom per person, the present requirement being a minimum of 400 cubic feet per person, excluding any space above 14 ft. in height. For a workshop of maximum height (14 ft. or more) this is equivalent to a floor area of 28 sq. ft. per person, whilst for a workshop say 9 feet high, it is equivalent to 44 sq. ft. per person. Recently made surveys[2] of existing factories of various types provide evidence that such densities are rarely attained. In most cases therefore the adoption of a figure of 400 cubic feet per person as a method of calculating the number of persons who may normally be expected to occupy a factory will lead to the provision of means of escape which may be greater than is necessary.

79. The survey figures indicate that the actual density of occupation of existing factories varies within wide limits, depending both upon the type of occupany and the particular operation being performed. We consider, however, that a figure of 75 sq. ft. per person may reasonably be adopted for the purpose of

[1] *Post-War Building Studies: No.* 16, *Business Buildings*, H.M.S.O., 1944.
[2] Quoted in the *City of Manchester Plan*, 1945, Appendix E.

calculating provision for means of escape in the normal factory. A higher population density, up to the equivalent of 400 cubic feet per person, should be adopted where crowded conditions may be expected, and in the case of heavy industry or other low-density occupancies it will be necessary to make a reasonable assessment of the maximum population of the factory. Where specially hazardous processes and materials are used or stored or handled, the provision of means of escape calls for special consideration in each case and the population density is no longer a determining factor.

SHOPS AND DEPARTMENT STORES

80. The difficulty of making counts of the number of people in buildings of these types is obvious. The problem of population density is further complicated by the wide variation in conditions which may be met. For example, the upper floors of a department store may normally only have a very limited number of people, yet at Christmas time or bargain sale periods, the same floors may be crowded.

81. It is difficult to assess the allowance that should be made for the latter conditions of use. Where there is satisfactory evidence that particular floors cannot or will not be used for bazaars or special sale displays, and with present-day methods of planning the floors intended for those purposes are usually pre-planned, we suggest a population density of 75 sq. ft. per person, calculated on open floor space. On those floors where such assurances cannot be given and the area may be used for bazaars, etc., the figure should be 10 sq. ft. per person. We would draw attention here to the London practice of basing the density on area of gangways. This is perhaps the ideal but as the layout of the sales counters may change we consider the value based on total floor area to be of more general use. For areas in which the circulating space is one-half the total area, the results given by the two methods are equal.

Summary of Recommended Population Densities

82. The following is a list of recommended population densities:

Halls for a closely seated audience with movable seats	5 sq. ft. per person.
Halls for a closely seated audience with fixed seats	Designed capacity.
Dance Halls	6-10 sq. ft. per person.
Restaurants	10 sq. ft. per person (calculated on dining area).
Retail Shops and upper floors of department stores (except as below)	75 sq. ft. per person.
Department stores—sales basements, ground floor and any upper floor used for bazaars or special sales displays	10 sq. ft. per person.
Offices	100 sq. ft. per person (calculated on gross floor area, excluding lavatories and staircases).
Factories	75 sq. ft. per person (see paragraph 79).

SECTION I. CONSTRUCTION IN RELATION TO PERSONAL SAFETY

GENERAL

83. The safety of the occupants of a building is affected by some of the factors considered in Part I, *e.g.* the fire resistance of structural elements. Other factors which depend both on the construction of a building and the use to which it is put have now to be taken into account. The use of inflammable surface finishes, for example, is an important constructional consideration, whilst such matters as whether or not people sleep in a building, the danger of panic in assembly buildings, etc. have to be considered in dealing with the characteristics of different occupancies. It is necessary to realize at the outset that the main structure of a building may have little bearing on the risk to life.

84. A vivid example of the life risk which may arise from causes not connected with the main structure of a building is afforded by the Cocoanut Grove Night Club fire in Boston, U.S.A., in 1942. In that disaster 500 people lost their lives in a "flash" fire attributed to inflammable decorations. The damage to the building itself, a reinforced concrete structure, was negligible. Similar conditions arose during recent fires in an hotel in America and a cinema near Paris, where inflammable linings were the main cause of the trouble.

85. These occurrences, which fortunately are not frequent, can be avoided only by strict limitation on the use of inflammable surface finishes. We have noted during the past four or five years an increasing tendency in this country to the use of combustible lining materials. This question is therefore considered in detail in paragraphs 87-98. We would note here that the danger from such hazards as inflammable decorations, serious though it may be, is outside the scope of this Report. We deal here only with those precautions which affect the structure or permanent finishings of buildings, but as inflammable decorations may well render useless such precautions, we would emphasize the need for particular attention being paid to that problem by the appropriate bodies.

86. The various structural precautions which have to be taken to ensure an adequate standard of safety for the occupants of a building may conveniently be considered under the following headings:

1. Precautions to minimize spread of flame on wall and ceiling surfaces.
2. Precautions to minimize movement of smoke and hot gases through the building.
3. Precautions to minimize danger from penetration of flame or heat through walls, floors and partitions, or from collapse of the structure, *i.e.* from growth of fire. This question involves recommendations relating to the fire resistance and size of buildings supplementing those already given in Part I.

MINIMIZING SPREAD OF FLAME ON WALLS AND CEILINGS

NATURE OF PROBLEM

87. This question has already been discussed in Part I of our Report in connection with dwelling houses, and recommendations were made regarding the use of different surface finishes in the light of experience in actual building fires, based

on the standard spread of flame test.[1] In dealing with the question as applied to buildings in general, several considerations have to be taken into account. In the first place it must be remembered that, in this country, we have been accustomed to the use of incombustible surfaces, such as plaster, which give immunity from flame spread. On this account no great attention has, until recent years, been given to the possible danger from the increasing use of various combustible materials such as plywoods and combustible building boards. The evidence of their effect on spread of fire is accumulating, however, and records of fires in huts, dwellings and occasionally larger buildings incorporating linings with Class IV surfaces suggest that the use of these materials causes serious danger to life.

88. The danger inherent in the nature of these materials is frequently increased by the presence of an air space behind them, the normal method of fixing being on timber studding or battens. This is particularly important in cases where a low flame spread surface is obtained by a thin facing of suitable material on a highly combustible backing, *e.g.* a skim coat of plaster on fibre-board. Such a combination cannot be regarded as equivalent to a homogeneous lining with a Class I surface if there is a concealed air space permitting spread of flame on the back of the board.

89. Special attention must be drawn to the use of hollow stud partitions covered with linings with Class IV surfaces. These are not only dangerous from the point of view of flame spread on the surface, but constitute a potential hazard in other ways. Firstly, fire may spread rapidly in the air space within the partition. Secondly, the presence of the partitions might conceal a fire in its early stages in an unoccupied room, and, when the outbreak had gained a firm hold, offer so little resistance to growth of fire that the lives of persons occupying the other rooms partitioned off might be seriously endangered. A floor area sub-divided by such partitions may indeed present a greater life risk than an open floor space with similar lining. In a recent fire in an office building, partitions of this kind were involved. Fire occurred during the day in some office supplies, and though it was discovered at the outset, attempts to use first-aid fire appliances were ineffective. Fire then spread so rapidly in the combustible partitions that two persons were cut off in one of the rooms and had to be rescued through a window.

EXISTING REGULATIONS

90. The comparative newness of this problem of surface spread of flame is reflected in the fact that it receives relatively little attention in existing codes and byelaws. Of those regulations which deal with the subject, the following may be mentioned as typical examples:

1. The London County Council and the City of Liverpool regulations governing the construction of buildings used as places of public entertainment prohibit the use of softwood [2] or other inflammable wall linings in any part of the premises. In addition, they do not permit cavities behind any linings.
2. The Home Office *Manual of Safety Requirements in Theatres, etc.* recommends that theatre buildings containing any considerable quantities of softwood wall covering should be graded as Class C, a class for which special fire precautions are required.

[1] See B.S. 476 or Appendix VII of Part I of our Report.

[2] Recent investigations indicate that all timbers except those weighing less than 25 lbs. per cub. ft. fall into Class III of the British Standard spread of flame classification. The lighter timbers fall into Class IV.

3. The Canadian Code limits the use of combustible linings in buildings of fire resisting construction. Combustible wall and ceiling finishes can only be used without an air space, and in places of assembly such finishes have to be treated to make them less inflammable.

LIMITATIONS ON USE OF COMBUSTIBLE LININGS

91. In considering the extent to which combustible linings can reasonably be allowed it is necessary to balance the fire risk which may arise from the use of these materials against their usefulness from other points of view such as insulating properties. It is also necessary to consider what precautions can be taken to minimize the risk where these linings are allowed. Where their use with an air space behind is unavoidable, the air space should be broken up into as small sections as possible, and special care should be taken to provide fire stops at wall, floor and ceiling junctions. Where large areas of linings with Class IV surfaces cannot be avoided fire breaks of incombustible materials should be provided. In the present state of knowledge of this subject it is not possible to lay down hard-and-fast rules, universally applicable, for the limitation of the use of combustible linings. As a Committee concerned with safety from fire we would naturally prefer to see incombustible materials used, as indeed they should be when they are equal in other respects to combustible materials, but we realize the necessity, especially at the present time, for maintaining a proper balance between fire risk and other factors. Some recommendations for the use of combustible linings in particular occupancies are given below.

Recommendations on Surface Finishes

92. It is necessary to make a distinction between surface finishes generally, and the linings of corridors, staircases and other escape routes. It is obviously essential that escape passages should be particularly free from any danger due to flame spread or the production of smoke by rapid burning of wall or ceiling linings. This point will be considered further in Section 2 in dealing with the constructional requirements for Means of Escape. It should be noted therefore that *the following recommendations do not apply to escape passages.*

Group A. ASSEMBLY BUILDINGS

93. The choice of surface finishes in assembly buildings involves considerations of acoustics and decorative effect as well as danger from spread of flame. The use of wood panelling, for example, is frequently desired. We are of the opinion, however, that in theatres, cinemas and other buildings accommodating a closely seated audience, and in dance halls, surface finishes should be restricted to those conforming to Class I or Class II in the surface spread of flame test. In other buildings in the assembly group we consider some relaxation might be accepted provided that exit facilities are increased. We recommend, therefore, that not more than 50 per cent. of the wall surfaces of such buildings might be in Class III materials if the remainder of the wall area and the ceiling have Class I surfaces, and the exit facilities are increased by 20 per cent. over the recommendations made in Section 2 of this Part of the Report.

Group B. TRADE, COMMERCIAL AND INDUSTRIAL BUILDINGS

94. There are two ways in which the question of surface finishes becomes important in buildings of this type; firstly, the use of combustible materials to form partitions; and secondly, the spread of fire in unoccupied suites of rooms. On account of these factors we cannot recommend the use of materials which allow

a very rapid flame spread, *i.e.* Class IV materials. The use of Class III materials for partitions might in some cases spread a growing fire with some speed, but in view of the fact that the occupants of buildings of this type are normally active and alert, it is not considered that the use of Class III linings would cause an excessive hazard to people in adjacent rooms partitioned off in this way. It is, therefore, recommended that surface finishes, in trade, commercial and industrial buildings should be limited to Classes I to III.

Group C. RESIDENTIAL AND INSTITUTIONAL BUILDINGS

95. *Flats and Maisonettes.* The conditions in these buildings as regards danger from flame spread are very similar to those in dwelling houses, which have already been dealt with in Part I of the Report. It is, therefore, suggested that the same recommendations should apply to the use of surface finishes in these cases, *i.e.* surface finishes should be not less than Class III subject to the limitations recommended in Part I.

96. *Hotels and Residential Schools.* It is necessary here to distinguish between public rooms and the floor areas used for bedroom accommodation. Dealing first with the latter, a somewhat different condition exists from that in flats and block dwellings, due primarily to the lesser degree of smoke separation between bedrooms and escape routes. In flats, the rooms are usually approached from the staircase or corridor by a lobby, giving a double separation from the point of view of restricting the spread of smoke and hot gases. In the bedroom floors of hotels and residential schools there is generally only a single separation between rooms and corridors. This involves a greater risk of the corridors becoming smoke-filled if fire starts in a bedroom and the door is left open. Added to this there is the fact that the travel distances along corridors are generally greater in such buildings than in blocks of flats, and the unfamiliarity of the occupants with the layout of the building is also a factor.

97. On account of these factors it is recommended that the wall and ceiling finishes of bedrooms in hotels and residential schools should be limited to Classes I and II. In public rooms, occupancy conditions are very similar to those in restaurants and similar assembly buildings. It is recommended, therefore, that surface finishes in these rooms should be subject to the recommendations set out in paragraph 93.

98. *Institutional Buildings.* It is obvious that a very high standard is desirable in this type of building and it is recommended that all wall and ceiling surfaces should conform with Class I. In institutions or departments where bedridden patients are not normally expected, however, Class II surfaces could be allowed.

MINIMIZING SPREAD OF SMOKE AND HOT GASES

99. Smoke-stopping is of great practical importance, but it is difficult to make specific recommendations on the matter because it depends so much on the layout of individual buildings. We deal here with the general principles.

100. In considering what precautions are desirable to minimize life hazard from spread of smoke, the primary object is to protect escape routes, and confine smoke and hot gases as far as possible to the part of the building in which fire originates. It is particularly important that staircases should not become smoke-logged. The provision of smoke-stops is closely associated with the means of preventing spread of fire. In many cases, it is true, the primary danger is from smoke rather than from heat or flame, as a smoke-filled atmosphere can cause panic when there is comparatively little danger from fire spread. In general, however, hot gases

have to be considered as well as smoke, and the protection of escape routes should be such as to provide a reasonable degree of fire resistance in the partitions, doors, etc. involved. Light timber partitions, for example, which might be quite smoke-tight, cannot be considered as satisfactory protection for escape corridors, as they might rapidly be involved in fire, and so become a hazard rather than a protection. The question of fire resistance requirements for partitions, etc. bounding escape routes will be considered in Section 2. It is necessary to consider here the general nature of the constructional features required for minimizing personal hazard from smoke and hot gases.

101. Openings and extraction devices designed specifically for smoke venting have been proposed. They are undoubtedly of value in specific instances, *e.g.* smoke extracts from basements, although these are perhaps in a different category as they are designed primarily to facilitate the work of firemen. In general, however, unless very carefully designed, such devices may create draughts which defeat the very object for which they were designed. We prefer a more fundamental approach to the problem.

102. In buildings with undivided floor areas it is essential that the staircases should be enclosed to keep them reasonably free from smoke, and prevent the passage of smoke and hot gases from one floor to another. In some buildings it may be desirable to provide a double separation between each floor and the staircase by introducing a lobby approach to the stairs. Buildings in which the floor areas are subdivided into rooms served by corridors may be considered to have a single separation between working floor area and staircase provided by the partitions, but the possibility of corridors becoming smoke-filled due to the door of a room being left open again necessitates the enclosure of all staircases. Somewhat similar conditions hold in the case of blocks of flats with the doors of the flats opening on to a common staircase. In this case, if individual rooms in the flats are approached from the staircase by a lobby or hall, it may be considered that there is a double separation between the staircase and the places where fire is most likely to start.

103. Smoke-stopping is thus mainly a matter of enclosure of staircases and the provisions made in Part I in this respect will, in general, afford the necessary protection if smoke-stop doors are provided to all openings. As this question relates to means of escape, however, it will be dealt with further in Section 2. In some buildings it will be desirable to have smoke-stop doors in the corridors at intermediate points. In school buildings, for example, the provision of such doors is, in some cases, a desirable safety measure. Asbestos curtains have also been used for smoke-stopping. It should be appreciated that fire-stop doors operated by fusible links should not be relied on for smoke-stopping. Obviously there may be enough smoke spread to prevent use of the escape route some time before the temperature rises sufficiently to operate these doors. If a smoke-stop is required at a point where a fire-stop door of the type mentioned is fitted, a separate self-closing door should be provided.

MINIMIZING GROWTH OF FIRE

104. In Part I of our Report recommendations were made for the grades of fire resistance of elements of structure, and also for the limitation of size of buildings according to construction and fire load. These recommendations were based on general considerations of volume of fire, which we dealt with by limitation of floor area and cubic capacity, fire fighting facilities and other factors. It is now necessary to consider these questions from the point of view of personal safety.

105. It is clear that there are cases in which fire growth, though important from the point of view of damage to property, has little effect on personal safety. A large warehouse building for example may be occupied by only a small number of people, normally all alert and able-bodied, and so able to leave the building quickly in case of fire. On the other hand, the question of fire growth becomes of primary importance from the point of view of life risk when, for some reason, there is liable to be a delay in the evacuation of the occupants of a building. A delay can arise in those cases where the occupants may not get early warning of an outbreak, or may not be in a physical condition to respond quickly to an alarm. Any delay in receiving warning of fire would affect particularly those occupancies where rooms or floor areas are unoccupied for substantial periods of time while there are people in other parts of the building. This applies to most residential buildings. An illustration of this is found in dwelling-house fires where the outbreak starts during the night in a living room downstairs and is not detected until the fire has gained a firm hold. Similar conditions are liable to arise in other types of residential buildings such as hotels, flats and residential schools, *i.e.* wherever there is a sleeping risk.

106. It is, of course, possible in any building for fire to start in an unoccupied room, but in buildings without sleeping accommodation and in one tenancy throughout, it is reasonable to assume that the normal traffic of the building would be sufficient to ensure early detection of a fire and adequate warning of the occupants. Consideration must, however, be given to the case of multiple tenancies, *e.g.* an office building subdivided among a number of tenants. In such a case, if fire broke out in an unoccupied suite of rooms it might reach a dangerous severity before being discovered. Also, available evidence indicates that the risk of fire incidence is higher in buildings divided up in this way than in similar buildings in one tenancy throughout. These considerations affect not only commercial buildings but also blocks of flats, hotels, and such premises as clubs where there may be a number of minor assembly rooms in one building.

107. As already noted, a further cause of delay in evacuation, and therefore of personal risk from fire spread, is physical disability in the occupants of a building. This applies particularly to institutional buildings where the occupants are dependent on the staff, but also, to some extent, affects residential buildings.

108. The constructional precautions necessary to minimize personal hazard from growth of fire in buildings can conveniently be dealt with under the following headings:

1. Precautions to minimize personal hazard from fire growth in buildings of incombustible fire resisting construction.
2. Precautions to minimize personal hazard from fire growth in buildings not of incombustible fire resisting construction.
3. Precautions to minimize personal hazard from fire growth in buildings occupied by different tenants or containing mixed occupancies.

BUILDINGS OF INCOMBUSTIBLE FIRE RESISTING CONSTRUCTION

109. It is a matter of common experience that in buildings of this type of construction there is generally a greater degree of life safety than in buildings with combustible elements such as timber floors. The term "fireproof" cannot be applied to such buildings in other than a loose, unscientific sense, yet there is support for the feeling of safety associated in the public mind with these buildings. This

feeling of security has been demonstrated in actual fires by occupants calmly watching from upper floor windows while firemen were fighting an outbreak on a lower floor. A very different reaction is apparent where the occupants of a building have no assurance of the fire resisting properties of the construction.

110. It must, however, be reiterated here that factors other than the combustibility and fire resistance of the main structure affect safety of life. Attention must particularly be paid to enclosure of staircases and the nature of partitions and internal surface finishes. A building in which the main structure is of incombustible materials and of a specified grade of fire resistance but has inflammable linings may produce a much greater life risk than one having timber floors and partitions but incombustible linings. The question of partitioning, so far as it relates to the separation of multiple tenancies, is discussed in paragraphs 129-134. The enclosure of staircases will be dealt with in connection with means of escape in Section 2.

111. Reviewing the recommendations made in Part I for grades of fire resistance of structural elements and maximum size of buildings of different types of construction, and taking into account the factors mentioned above, it is considered that the figures given in Part I for Types 1 to 3 construction[1] are satisfactory.[2]

BUILDINGS NOT OF INCOMBUSTIBLE FIRE RESISTING CONSTRUCTION

112. In these buildings it is necessary to take account of the fact that forms of construction using structural elements such as unprotected steelwork or timber floors can present a danger to life due to the risk of early collapse in a fire or the rapid penetration of flame. For this reason a more severe limitation of size than was recommended in Part I of our Report may be desirable as an additional precaution. The types of construction which fall under this heading are types 4, 5, 6 and 7.

113. It is obvious that in buildings where the floors and other structural elements have only a negligible fire resistance there is a considerable personal hazard from fire growth. In a building with open timber joist floors and plain-edged boards, for example, the entire building might be involved in fire in a very short space of time. The addition of plaster ceilings, giving a useful increase in fire resistance to the floors, would materially restrict the rate of fire growth, and so increase the possibility of escape. In buildings with a high personal risk we consider that in no case should the floors or any structure supporting them have less than half-hour fire resistance.[3] We recommend, therefore, that the construction of all buildings more than one storey in height for Group A and Group C occupancies (assembly, residential and institutional buildings) should have a fire resistance not less than that of Type 4 construction.

This recommendation alone, however, would not constitute a complete safeguard against growth of fire, as Type 4 construction is not fully protected even in relation to low fire loads. Moreover, consideration must be given to the use of Type 5 construction in multi-storey buildings for Group B occupancies (Trade, Commercial and Industrial Buildings) and to single-storey buildings in General in Types 5, 6 and 7 construction. Our recommendations for these buildings are given below.

[1] See Appendix IV for Table of Proposed Minimum Fire Resistance Requirements for Graded Types of Construction (Reproduced from Part I of our Report).

[2] See, however, Section 2 of this Part for buildings with only one staircase.

[3] A timber joist floor with plaster ceiling and tongued and grooved flooring will satisfy this recommendation.

LIMITATION OF SIZE OF MULTI-STOREY BUILDINGS OF TYPE 4 CONSTRUCTION

114. Take, for example, a building of Type 4 construction with low normal fire load. The maximum cubic capacity recommended in Part I is 500,000 cub. ft. which we limited to occupation by one tenant. However, if fire occurred in a building of this size and type of construction occupied as flats or separate offices, there would be greater risk of delay in detection and in warning, thus creating a greater life risk especially when the sleeping risk arises. A further limitation of size is therefore desirable. The effect of such a limitation is to restrict the number of lives which are endangered, rather than to secure the safety of the occupants as individuals, which depends primarily on the means of escape. Indirectly, however, a restriction on the number of persons affected increases the possibility of escape for each individual by making it more readily possible for everyone to be warned of fire, or, in the last resort, rescued by the fire service. Recommendations are given below for the maximum size of buildings of Type 4 construction for occupancies in which personal safety is a determining factor.

Group A. Assembly Buildings

115. It has already been pointed out in paragraph 106 that a life risk may arise from an outbreak of fire in an unoccupied room, particularly if the building is not of fully protected fire resisting construction. To some extent this affects all assembly buildings as fire might start in a cloakroom or store while the main assembly room was occupied. Provided, however, that there are no highly combustible finishes, the possibility of the fire assuming serious proportions before being discovered is not unduly serious in buildings where all the accommodation serves one main assembly room. Our main concern in the present instance is with buildings in which there are a number of assembly rooms which may not all be occupied simultaneously.

116. It is useful, as a concrete example, to consider a fairly common type of building in which these conditions occur; for instance, a club building of two storeys in which there are a number of small rooms on the ground floor, and a main hall on the upper floor where it is easy, from a constructional point of view, to get a large, clear floor space. This layout is fairly typical of minor assembly buildings and restaurants where, for example, private dances may be held; the kind of assembly building for which Type 4 construction would most likely be used. The obvious source of danger in such a building from the point of view of delay in warning of fire, is the possibility of an outbreak in a downstairs room while the hall upstairs is occupied. On account of this possibility, and in view of the number of lives at risk, certain size limitations, additional to those provided in Part I of the Report, seem necessary. In the first place, a limitation of floor area to say 2,500 sq. ft. would ensure that only a moderate number of people (a maximum of about 400 on the basis of 6 sq. ft. per person) could be assembled on any one floor.

117. It would be undesirable for such a number of people to be gathered on each of several floors if all floors were served solely by the same exits. If, however, any upper floor used for assembly had one of the stairs serving it entirely cut off from the other parts of the building and leading direct to the open air, this condition could be accepted. Otherwise it is desirable that the total number of people in the building should be limited, and it is proposed that the maximum number should not be greater than 500.

118. In addition to these limitations it is desirable to introduce a further height restriction so as to avoid having a considerable number of people coming down many

flights of stairs in conditions which might cause panic. It is proposed that there should not be any floor used for assembly at a greater height than 20 ft. above ground, although this would not preclude the provision of such accommodation as caretakers' quarters at a greater height. In this matter also, an exception could be made in the case of an upper floor having an entirely independent enclosed and protected stair, as described above.

Group B. Trade, Commercial and Industrial Buildings

119. We consider that the limitations of size imposed by our recommendations in Part I are adequate from the point of view of personal safety for all Group B occupancies except offices. These require special consideration from the standpoint of personal safety as the figure of 500,000 cub. ft. proposed for low normal fire load occupancies in Type 4 construction in Part I is higher than can reasonably be allowed where special considerations of personal safety are involved. Many office buildings are in multiple tenancy, and those in single tenancy may later become multiple tenancies. The increased hazard from multiple tenancies has already been pointed out. The letting requirements in such buildings are liable to cause frequent changes in the layout of partitions and to some extent in the nature of contents. The fire resistance of the separation between tenants may not be adequately maintained, and individual tenants are less likely to pay attention to "good housekeeping" from the fire point of view than is the occupier of a building in one tenancy throughout. On account of these factors we recommend that the cubic capacity of office buildings of Type 4 construction should be limited to 250,000 cub. ft.[1]

120. A limitation of floor area is not so necessary in Group B as in Group A occupancies because the population density is not so high and the total number of persons in a building will therefore be much less. We consider that the maximum floor area resulting from the limitations on height and cubic capacity recommended in Part I and the further limitation on cubic capacity recommended above will be satisfactory.

Group C. Residential and Institutional Buildings

121. *Residential Buildings.* In dealing with the question of size limitation of this type of building, it is useful to consider it in relation to blocks of flats of the traditional single-staircase type with timber floors and plaster ceilings giving an approximation to Type 4 construction. Such buildings are very numerous and experience indicates that there is no undue life risk in them. It seems reasonable, therefore, to deal with them as a starting point for the discussion of residential buildings in general.

122. In buildings of this type the number of flats per floor served by the single staircase is commonly two and does not usually exceed four. It may be noted that this is the maximum number allowed by the L.C.C. means of escape requirements for buildings in which the floors are not of "fire resisting materials." On this basis it seems reasonable to limit the floor area to 2,500 sq. ft. Taken in conjunction with the height limitation of 50 ft. given in Part I, this gives a maximum cubic capacity of 125,000 cub. ft.[2]

123. It is now necessary to consider the figures for floor area and cubic capacity in relation to residential buildings in general, including hotels and residential

[1] This figure is not agreed by Mr. Thorowgood, who is of the opinion that the maximum size should be 125,000 cub. ft.

[2] For definition of height as used in this Section, see Part I, paragraph 109. (The recommended height limitation of 50 ft. is subject to a tolerance of +5 ft.)

schools. In some cases there may be factors such as greater freedom of circulation and attendance of night watchmen which would reduce the risk of undetected fire spread. There are, however, other considerations which tend to cancel out such advantages. In hotels, for instance, the occupants are much less familiar with the layout of the building than in the case of flats. On balance, no change in the figures seems warranted. We recommend, therefore, that residential buildings of Type 4 construction should generally be limited to a floor area of 2,500 sq. ft. and a cubic capacity of 125,000 cub. ft. In two-storey buildings there is reason for allowing an increased floor area on account of the reduced number of persons involved, and the fact that the occupants can more readily escape unaided from upper floor windows without risk of serious injury. We, therefore, recommend that the maximum floor area of two-storey buildings in Type 4 construction should be 5,000 sq. ft.

124. *Institutional Buildings.* This type of building requires special consideration from the point of view of the difficulty of rescue work involving bed-ridden patients. Fully protected fire resisting construction is obviously desirable for institutional buildings. The use of Type 4 construction, however, may be considered justifiable for low buildings of limited floor area. It is recommended that the height should be limited to two storeys and the floor area to 2,500 sq. ft.

LIMITATION OF SIZE OF MULTI-STOREY BUILDINGS OF TYPE 5 CONSTRUCTION

125. As the floors of buildings in this type of construction do not possess any specified grade of fire resistance, it is necessary to assume, for the purpose of recommendations, that their fire resistance may be negligible and they may therefore collapse or permit flame penetration very early in a fire. It is evident that such a form of construction is not suitable for occupancies involving a sleeping risk or in which persons are assembled in large numbers. We recommend therefore that it should not be used for multi-storey buildings for Group A or Group C occupancies.

126. As with Type 4 construction we consider that the only building in Group B occupancies which requires further limitation of size is the office building. The maximum size recommended in Part I for low normal fire load occupancies in Type 5 construction is 250,000 cub. ft. We recommend that the cubic capacity of office buildings of Type 5 construction should be restricted to 125,000 cub. ft.[1]

LIMITATION OF SIZE OF SINGLE-STOREY BUILDINGS OF TYPES 5, 6 AND 7 CONSTRUCTION

127. The maximum size recommended in Part I for low normal fire load occupancies in single-storey buildings in Types 5 and 6 construction is 300,000 cu. ft. A single-storey building of this cubic capacity would occupy a considerable floor area. We do not consider that a building of such a size would constitute any risk to life if used for a low normal Group B occupancy, but in view of the absence of any specified degree of fire resistance in the roof we think it advisable to limit the size of buildings for Group A and Group C occupancies in these types of construction. We recommend that single-storey buildings of these types for Group A and Group C occupancies should not exceed 5,000 sq. ft. in floor area. A similar restriction on floor area is necessary for buildings in Type 7 construction, as the maximum floor area based on a height of 12 ft. 6 in. and the maximum cube of

[1] Mr. Thorowgood's view is that the maximum size should be 50,000 cub. ft.

75,000 cub. ft. recommended in Part I would be 6,000 sq. ft. We recommend that single-storey buildings in this type of construction for Group A and Group C occupancies should not exceed 2,000 sq. ft. in floor area.

Summary of Recommendations for Size Limitation of Buildings or Divisions of Buildings not of Incombustible Fire Resisting Construction

128. The following summary of the above recommendations may be helpful:

1. Multi-storey Buildings of Type 4 Construction.

   Assembly Buildings.

   a. The floor area on any one storey should not exceed 2,500 sq. ft.
   b. The maximum population throughout the building should not exceed 500.
   c. Any floor area used for assembly should not be at a greater height than 20 ft. This would not preclude such accommodation as caretakers' quarters being at a greater height.

   Recommendations b. and c. would not apply to any floor having one of the stairs serving it enclosed in such a way as to cut it off from the rest of the building and give direct access to the open air at ground level.

   Office Buildings.
   Maximum cubic capacity, 250,000 cub. ft.

   Residential Buildings.

   a. Maximum cubic capacity, 125,000 cub. ft.
   b. Maximum floor area, 2,500 sq. ft. for buildings more than two storeys in height; 5,000 sq. ft. for two-storey buildings.

   Institutional Buildings.

   a. Maximum floor area, 2,500 sq. ft.
   b. Maximum height, two storeys.

2. Multi-storey Buildings of Type 5 Construction.

   Assembly Buildings.
   Not recommended.

   Office Buildings.
   Maximum cubic capacity, 125,000 cub. ft.

   Residential and Institutional Buildings.
   Not recommended.

3. Single-storey Buildings of Types 5 and 6 Construction.

   Assembly, Residential and Institutional Buildings.
   Maximum floor area, 5,000 sq. ft.

4. Single-storey Buildings of Type 7 Construction.

   Assembly, Residential and Institutional Buildings.
   Maximum floor area, 2,000 sq. ft.

BUILDINGS OCCUPIED BY DIFFERENT TENANTS OR CONTAINING DIFFERENT OCCUPANCIES

SEPARATION BETWEEN DIFFERENT TENANTS

129. This is a question to which a brief reference was made in Part I of our Report, whilst the added risk from multiple tenancies has already been noted in paragraph 106 of this Part. It is necessary to make provision against this by separation, of a suitable grade of fire resistance, between the different tenants.

130. In a building of low fire load and fully protected construction, *i.e.*, Type 3 construction, if the separation between each tenant has a fire resistance of one hour, which is the minimum recommended for the elements of structure in Type 3 construction, the building would be divided into a number of sections each of which should contain a fire. In flat construction this is in accordance with good modern practice and the need for it is readily accepted. In office buildings and factories, where there is no sleeping risk, the need for an equivalent standard may not seem so evident. Having regard, however, to the fact that each tenant is exposed to the risk from neighbouring tenancies, over which he has no control, we consider that the practice normally followed in flats should be adopted as a principle for all buildings. We recommend, therefore, that parts of a building occupied by different tenants should be separated by construction having the same grade of fire resistance as the minimum recommended for the elements of structure of the building (see Appendix IV of this volume).

131. In buildings which are not of fully protected construction the value of the separation between different tenants on the same storey will be limited by the fire resistance of the floor separation. In principle, therefore, no useful purpose would be served by recommending more than half-hour fire resistance in the partitions separating tenants in buildings of Type 4 construction. Nevertheless, in certain occupancies in buildings of Type 4 construction, it might be considered desirable to recommend partitions having one-hour fire resistance between tenants. This affects principally blocks of flats and we deal specifically with these in paragraphs 133 and 134.

132. There has to be considered also the effect of door openings in the walls separating the different tenancies. The recommendation in Part I that openings in fire resisting walls should be protected by doors of the same grade as the wall would prove onerous if applied generally to the separation between tenancies. Regard must be paid to the size of the parts of the building occupied by the different tenants, the type of occupancy and the personal hazard involved, in deciding what standard of protection should be provided to openings in the dividing walls. It is recommended that where any abnormal risk occupancy or any occupancy of moderate or high fire load is concerned, the principle of providing a door of fire resistance equal to that of the wall should be observed; in any occupancy involving a sleeping risk doors should be of fire-check type (half-hour fire resistance); whilst in all other cases no special door need be provided unless called for under a means of escape requirement.

SEPARATION BETWEEN FLATS OF TYPE 4 CONSTRUCTION

133. It should be noted that, in blocks of flats of the traditional type of construction with timber floors, the dividing walls between individual flats are often of load-bearing masonry and of more than adequate fire resistance. Future developments, however, may well call for the more frequent use of non-load-bearing partitions between flats, and it is desirable that the fire resistance requirements for these should not be more stringent than is required from the point of view of life safety.

134. The application of the general principle stated in paragraph 130 would allow the use of half-hour walls between flats. This represents a lower standard than has been adopted, in Part I, for the party walls of small dwelling houses. Also, a building with half-hour separation both horizontally and vertically would tend to allow more rapid fire growth than a building of traditional type with, say, 9 in. brick walls between flats. We do not, however, consider that the adoption of a half-hour standard for walls between flats would introduce an unduly high

life risk. It is desirable, furthermore, to avoid the inconsistency of requiring different standards of fire resistance in floors and partitions, when any increase in the fire resistance of the partitions may be made ineffective by the earlier failure of the floors. Special attention should, however, be given to the question of structural stability and resistance to damage of walls with half-hour fire resistance.

LIMITATION OF SIZE OF BUILDINGS CONTAINING DIFFERENT OCCUPANCIES

135. In Part I of our Report the maximum permissible size of buildings or divisions was considered in relation to the fire load classification of the occupancies involved. The figures given did not, however, apply to the case where there is more than one type of occupancy in the same building, *e.g.* where the ground storey is used as shops and the remainder as flats, or where part is used as a factory and part for storage. This question of mixed occupancies involves considerations of personal safety as well as fire load classification, and it was therefore deferred for consideration at this stage. The complications that may arise in practice due to the numerous possible combinations of occupancies are such that no detailed analysis is possible, and accordingly the discussion which follows is primarily designed to illustrate principles.

136. A completely satisfactory treatment of this question can only be obtained in buildings of fully protected construction. In these, each occupancy should be fully protected in relation to its own fire load, and the separation between them should have a fire resistance corresponding to the higher fire load. This principle has already been recognized in Part I in dealing with the question of storage space required in connection with occupancies of low or moderate fire load. It was recommended there that, if the storage space were separated from the remainder of the building by construction of an appropriate grade of fire resistance, it need not be taken into account in calculating the fire load of the building as a whole. In the general case the principle involved is that the limitation of size of parts of fully protected buildings in mixed occupancy can be determined for the occupancies separately, applying the figures given in Part I.

137. Even in buildings which are not fully protected it is possible to provide a complete and effective separation between the different occupancies. In an office block, for example, the main part of which is of Type 4 construction, if the ground storey is used as shops and the structural elements in the ground storey and the floor over are of 2 hours' fire resistance, the structure would resist a burnout in the ground floor shops. In such a case the cubic capacity allowable for the offices and shops can be determined independently of each other.

138. Consideration must, however, be given to buildings in which complete separation is not provided. This applies to buildings graded according to the fire load of the main occupancy, in which it is desired to use a limited part for an occupancy with a higher fire load. This matter is of considerable importance to building owners and users from the point of view of avoiding expensive structural alterations or precautions.

139. Here it is necessary to classify a building or division as a whole on the basis of the occupancy which includes the greater part of the cubic capacity. This, however, permits some increase in the extent of the risk where a building is of the maximum size allowable for the main occupancy and yet contains a secondary occupancy of higher fire load. It is now necessary to consider the effect of this relaxation of the conditions laid down in Part I.

140. Consider an office building of 500,000 cub. ft. in Type 3 construction in which it is desired to use part of the ground floor for a secondary occupancy of 2,500 sq. ft. high fire load storage. If this were used solely as an office building, no limits of size would be imposed by Part I. On the other hand, Type 3 buildings used for high normal fire load occupancies throughout and not sprinklered are limited to a height of 50 ft. and a cubic capacity of 125,000 cub. ft. In considering the possible effect of a fire in the storage area, it is necessary to take account of planning and form of construction. A building of 500,000 cub. ft. in Type 3 construction might be, say, a framed structure of 5,000 sq. ft. floor area and 100 ft. high. In contrast to this we could have a building with load-bearing masonry walls and concrete floors, 20,000 sq. ft. floor area and 25 ft. high.

141. In the case of the high, framed building, 2,500 sq. ft. of high fire load storage space would occupy half the floor area of the building. A fire in this space might cause the collapse of important stanchions, and so endanger the stability of the whole structure. On the other hand, the spread of fire upward through the various floors of such a building would be a comparatively slow process giving opportunity for control by fire fighting. In the low building no exceptional danger would arise from collapse of the structure, but horizontal spread of fire might be comparatively rapid.

142. While these differences affect the nature of the risk caused by mixed occupancies in buildings which are not fully protected, it is not considered that in practice the differences are such as to warrant separate treatment for buildings of different layout and type of structure. In high buildings, however, it is desirable that any instances such as that given above should be considered individually.

143. It should be stated here that no considerable departure from the extent of risk represented by the limits of size given in Part I of our Report can be recommended. It has been pointed out in paragraph 138, however, that it is desirable, from a practical point of view, to make some concession for mixed occupancies. In the following recommendation an attempt has been made to balance these factors. It is considered that, in general, the part of the building occupied for the use involving the higher fire load should be limited in cubic capacity to half the figure given in Part I for buildings in which the higher fire load occupancy is the only one. For instance, in the example already dealt with, the part used for storage should not exceed 62,500 cub. ft.

144. Where the main occupancy is residential, however, special consideration must be given to the question of personal safety. A common example of the type of building involved is one with trade premises or shops (moderate fire load) on the ground floor and flats above. The obvious danger in such a case is that an undetected fire in the moderate fire load occupancy may reach a dangerous intensity before the people in the residential part of the building get warning. On this account it is desirable to introduce more stringent limitation of the extent of the secondary occupancy than is necessary in other cases. It is suggested that the secondary occupancy should not have a greater cubic capacity than one-quarter of the figure given in Part I of the Report for buildings which have a corresponding fire load throughout. Further, we recommend that a secondary occupancy of high fire load should not be incorporated in any residential building.

145. The following Tables show the effect of the above recommendations in the case of unsprinklered buildings containing normal occupancies. The appropriate figures for abnormal occupancies and sprinklered buildings can be obtained by applying the above recommendations to the figures given in Part I of the Report.

Limitation of Secondary Occupancies of Fire Load Higher than Main Occupancy—Normal Occupancies—Buildings not Sprinklered

Table 2. Main Occupancy—Low Fire Load

Construction type	Max. cub. capacity of building or division (cub. ft.)	Max. cub. capacity of secondary occupancy (cub. ft.)		
		Moderate fire load		High fire load
		Non-residential buildings	Residential buildings	Non-residential buildings
3	No limit	125,000	62,500	62,500
4	125,000 to 500,000 *	62,500	31,200	25,000
5	125,000 to 250,000 *	25,000	—	12,500

* Depending on occupancy (see para. 128 and Part I of our Report).

Table 3. Main Occupancy—Moderate Fire Load

Construction type	Max. cub. capacity of building or division (cub. ft.)	Max. cub. capacity of secondary occupancy of high fire load (cub. ft.)
2	750,000 500,000*	125,000
3	250,000	62,500
4	125,000	25,000
5	50,000	12,500

* Depending on accessibility—see Part I.

146. The example already given of a high office building with storage space on the ground floor points to a further precaution which is desirable in mixed occupancies, *i.e.* limitation of the floor area of the secondary occupancy. The figure of 62,500 cub. ft. which has been arrived at for the permissible capacity of the storage space in the example (see para. 140 and Table 2) would, on the basis of 12 ft. 6 in. storey height, involve a floor area of 5,000 sq. ft. This area would occupy the entire ground floor of the high building. From the fire fighting point of view this area, filled with combustible material to such an extent as to constitute a high fire load, might produce a fire which could not be readily controlled and would endanger the stability of the building as a whole. If the storage space were spread over two floors, the fire resistance of the floors, though not adequate to prevent spread of fire from one floor to the other, would make it easier for the fire service to gain control of the outbreak. A limitation of the floor area occupied by the higher fire load occupancy on any one floor is thus a safeguard minimizing the added risk due to mixed occupancy. It is considered that this factor would be adequately taken into account if the floor area on any one floor were restricted to 5,000 sq. ft. for moderate fire loads and 2,500 sq. ft. for high fire loads.

SECTION II. MEANS OF ESCAPE

GENERAL

147. In Section 1 of this part of our Report we considered the effect on personal safety of various factors connected with the construction and occupancy of buildings. It is now necessary to deal with the design of structural means of escape, the adequacy of which is perhaps the most important factor affecting life safety in a building where fire occurs. The subject is one which has an extensive administrative side, but we would emphasize that we are here concerned solely with the technical questions involved and would note again that our recommendations are intended to refer only to new buildings.

148. In order to make clear at the outset what we propose to consider under the heading "means of escape," we have adopted the following definition of the term: "Structural means which form an integral part of the building, whereby persons can escape by their own unaided efforts." Some qualification of this definition is necessary in relation to hospitals and similar institutions where patients depend on staff for their removal, but if it is appreciated that our Report is not concerned with such items as lifts, ropes and other devices of this kind, the qualification need only be borne in mind generally.

149. Fundamentally, means of escape is but one aspect of the wider problem of circulation within a building. The latter provides for ingress and egress of all users, and for general movement within the building. The architect looks at this question primarily from the point of view of use and economy of constructional cost. There are no conclusive methods by which these points can be assessed. Each building must be treated on its merits according to site and other local circumstances. In view of the close relation between normal circulation and means of escape it is evident that the latter cannot be divorced from general planning considerations and treated by a series of hard-and-fast rules. Accordingly it is only possible to establish certain principles which take into account the special conditions arising in a fire.

150. Dealing with the subject under broad, general headings, it can be said that in making provision for the escape of occupants in case of fire in any building it is necessary to provide exits:

1. In suitable number and location;
2. Of adequate width; and
3. Of suitable construction.

The word *exit* in this connection includes corridors, staircases, exit doors, and all other means of passage by which the people in a building may reach a place of safety outside.

151. The relative importance of these different factors in any particular case varies considerably according to the type of occupancy, the layout of the building, and the number, distribution, and state of mind and body of the people in it. A large public hall, for instance, obviously presents an entirely different problem from a block of flats. In an assembly building there would be an immediate crowding of people round the exits on warning of fire being given, and the important point would be to have these wide enough and suitably planned to discharge all the people safely in a short time and so avoid crushing and panic. In a residential building the number of people might, by comparison, be quite insignificant, so that questions of crowd movement and exit width would not necessarily arise.

On the other hand, the occupants might not get warning until some time after the outbreak of fire, so that the construction of the staircases to provide protection against smoke and hot gases would be a vital matter.

152. Before entering into detailed discussion on each of the above factors it will be useful to consider them briefly in order to get some idea of the scope of the subject. So far as number and location of exits is concerned, two points require to be considered, firstly travel distance and secondly alternative egress. It is important to limit the distance which the people in a building have to travel to reach a staircase or exit door, partly to prevent confusion and panic, and partly because of the difficulty of movement in the smoke-filled atmosphere which may be caused by fire. As regards alternative egress, it is obviously desirable to have at least two escape routes from any part of a building. In some buildings of limited size, however, taking into account the possibility of rescue by the fire service, a single staircase can be accepted, but the maximum height and floor area must be restricted. Where large crowds are concentrated, as in assembly halls, it is generally necessary to have more than two exits, to avoid having an unduly large number of people crowded round any one exit.

153. In investigating the width of exits required under specified conditions it is necessary to know the discharge value of exits of different width. This requires consideration of the factors involved in the movement of numbers of people. It is necessary, for example, to examine the available data on rates of movement on staircases and through exits, and to deal with the problem of the interaction of moving streams of people from a series of floors.

154. Besides having to consider a variety of possibilities in the general planning of escape routes as regards number, position and width of exits, the designer is responsible for assuring that their construction is such as to provide the safest possible conditions for people escaping from a fire. Failure to attend to such matters as enclosures of staircases has led to serious loss of life in buildings where fire protection in other respects was of a high standard. Apart from this the question of construction of means of escape involves numerous matters such as the nature of surface finishes on escape routes and the direction of opening of doors. Some of these points are less vital than others, but all, in some degree, affect the safety of people who are attempting to make their way out of a building which is on fire.

155. The conditions in different buildings from an escape point of view differ so widely that it is difficult to frame a set of rules which can be applied indiscriminately to all types of buildings. This fact, together with the unpredictable human element which affects all life safety problems, accounts to a large extent for the wide variations which are seen in the requirements of existing codes on means of escape. Certain codes overcome the difficulty in some measure by making separate sets of rules for the various occupancy groups. There may be mentioned, for example, the Home Office *Manual of Safety Requirements in Theatres and other places of Public Entertainment*, which deals with only one type of occupancy.

156. The administrative aspect must also be considered. It is difficult, if not impossible, to write a code which will apply with legal precision in all the widely varied cases which are met in administrative practice. In the last resort the decision whether a particular scheme for means of escape is satisfactory must rest on the experience of the competent authority, so that a code should lay down guiding principles rather than binding requirements. Much of our present knowledge of this subject is represented by the requirements of existing building codes and Byelaws. These embody the results of cumulative experience over many years of administrative and legislative work, and are of particular importance in

this subject, which does not lend itself to precise observation or analysis. In this section, therefore, considerable attention has been given to these existing codes.

157. A complete consideration of the subject of means of escape involves many matters of detail, some of which are applicable only to particular occupancies. For the purpose of a detailed code it might be found desirable to adopt some subdivision into occupancy groups. For the present purpose, however, we have thought it better to deal only with general principles and the subject is considered under the main headings already indicated in paragraph 150.

NUMBER AND LOCATION OF EXITS

158. No simple formula for number of exits can be given which would apply to all types of construction and occupancy. It is here that we meet for the first time in specific form the relation between means of escape and general circulation to which we referred in paragraph 149. The question involves a multiplicity of factors of planning, construction and occupancy, and it must be recognized that the experienced architect's sense of proportion in producing a result which is satisfactory from the point of view of normal circulation will go far towards meeting requirements for escape.

159. As mentioned in paragraph 152, there are, from the life safety standpoint, two broad aspects of the subject which have to be considered. First, there is the question of the safe distance which people can be expected to travel to an exit under fire conditions. Second, provision has to be made for alternative egress, generally by arranging for at least two escape routes from any point in a building, or in the case of large crowds, providing a number of discharge points suitably distributed. In looking at this question of alternative egress, attention should be given to the location of the alternative escape routes, so that a fire which affects one of them will not be likely to put the others out of use also. Special consideration must be given to the question of single staircase buildings, in which the only alternative egress may be by fire service rescue appliances. This condition can obviously only be accepted in buildings of limited size in which the occupancy does not involve any exceptional hazard.

160. It is appropriate, then, to consider number and location of exits under four headings:

1. Travel Distance.
2. Minimum Number of Exits.
3. Location of Exits.
4. Limitation of Size and Occupancy of Single Staircase Buildings.

TRAVEL DISTANCE

161. Travel distance is important from two points of view, first, general circulation under fire conditions, and, second, the safety of people who have to pass through a smoke-filled atmosphere. So far as the former is concerned, it has already been noted that the question of circulation under escape conditions is but one part of the problem of circulation under the normal conditions of use of a building. The same number of people may be involved, but they will generally have to be cleared in a shorter space of time, and any delay will cause an intensification of mental reaction. In normal circumstances, delay caused by widely spaced or inconveniently positioned stairs may cause annoyance, but in the event of fire these hindrances tend to cause panic. There is, moreover, the possibility of one staircase or exit being blocked, say by smoke. This may involve a double journey on the part of the occupants who, having been warned of fire, may have to try

first one staircase and then another. Unfamiliarity with escape routes is a further factor which needs consideration. In the course of normal circulation people usually leave buildings by the same routes as those by which they enter and so become familiar with them. Ideally, all escape routes should be used for normal circulation, but this is not always possible, and emergency exits are frequently in positions where their presence is not readily noticed. Unfamiliarity with escape routes can, of course, be entirely or largely overcome by fire drills, where it is possible to hold these, or by prominent marking of exits. Except, however, in such instances as places of public entertainment, where stringent control over exit marking is maintained, and premises such as residential schools where regular fire drills can be carried out, the element of unfamiliarity is always liable to arise.

162. So far as movement in a smoke-filled atmosphere is concerned, the ideal condition should be that the occupants of a building should make their escape before there is any appreciable accumulation of smoke and hot gases in corridors and escape routes generally. Unfortunately this condition is not always realized. Fire may start in an unoccupied room, and, when the door is opened, sufficient smoke may be emitted into the corridor to make evacuation conditions uncomfortable if not dangerous. Much then depends on the stage which fire has reached when the alarm is given and on the layout of the building from the point of view of smoke-stopping. These points are important when we consider the significance of the travel distance factor in different types of occupancy and construction, and in buildings with different types of planning.

TRAVEL DISTANCE IN RELATION TO OCCUPANCY

Group A. ASSEMBLY BUILDINGS

163. In occupancies of this group it is reasonable to expect that there will be early warning of fire, and that passage of occupants through a smoke-filled atmosphere will not be a major consideration. That possibility cannot be completely excluded, however, and some limitation of travel distance is desirable on that account, but the major concern is the provision of an adequate number of exits so distributed that no one exit should have to cater for a large number of persons. Where escape may be impeded by fixed seating, exhibition stands, etc. it is also important that gangways should be arranged to lead directly to exits.

Group B. TRADE, COMMERCIAL AND INDUSTRIAL BUILDINGS

164. There will be considerable variation in this group, especially among different factories according to the nature of the contents or materials being handled. Those which fall into the abnormal group of occupancies as defined in Part I will, in general, present the greater risk in this respect also. It has already been pointed out that the possible presence of smoke on escape routes makes a limitation of travel distance desirable, and that panic may arise when excessive distances have to be travelled in search of an alternative way out if the normal staircase or exit is unsafe. The term "panic" in this connection has a somewhat different scope from that which it has in the case of an assembly building. Panic in an assembly audience results in a crowd jamming the exits and causing injuries by crushing quite apart from injury by fire. In the type of building now being considered individuals as well as groups may become panic-stricken. Lives may be lost, for example, through fear of using staircases in which there is some smoke but which would actually give safe passage out of the building.

Group C. RESIDENTIAL BUILDINGS

165. Because the occupants of these buildings may be asleep there is greater chance than in any other type of building that fire will develop and obtain a good

hold before it is discovered. Moreover, if the occupants are in bed when an alarm is given, they are less likely to be fully alert or prepared for evacuation and will then be more liable to panic. This applies particularly to buildings such as hotels where the route to exits involves travelling along unfamiliar corridors and possibly turning corners. In some residential buildings, on the other hand, the increased danger is offset by the occupants' familiarity with escape routes; and in buildings such as blocks of flats where the living accommodation is grouped round staircases without corridors external to the rooms or flats, the question of travel distance does not really arise.

Existing Practice

166. Existing codes vary considerably in their treatment of the occupancy factor in relation to travel distance. Considering assembly buildings, for example, the B.I.N.C. code applies the lowest travel distance figure to this occupancy (75 ft. in the case of ordinary construction), while the N.F.P.A. Code, in the case of floors near ground level, allows the highest travel distance figure (150 ft.), making them rank with occupancies having the lowest risk. The Canadian Code, on the other hand, makes no distinction between different occupancies.

167. In the light of the foregoing paragraphs, it seems that there are broad, general grounds on which a distinction might be made between different types of occupancy, but that the practical application of any such distinction is by no means agreed or straightforward. Many hotel buildings, for example, have quite long corridors, giving travel distance conditions comparable with those which exist in office buildings, where there is no sleeping risk. It can reasonably be maintained, however, that with appropriate types of construction in each case, and possibly special attention to exit marking and smoke-stopping in hotels, there would be no serious difference in life risk.

168. The question of travel distance in different occupancies is inevitably affected by considerations of construction and the additional precautions such as fire drills which can reduce the life risk in those buildings where it is higher than normal. The survey of existing buildings given in the U.S. Bureau of Standards publication *Design and Construction of Building Exits*, is of interest as showing how difficult it is to differentiate conclusively between different types of occupancies as far as existing practice is concerned. Some figures for maximum travel distance extracted from that Report are given in Table 4. These all relate to buildings of fire resisting construction, though this would not necessarily exclude significant differences in minor constructional features such as partitions and finishes.

TABLE 4. MEASURED TRAVEL DISTANCE IN EXISTING BUILDINGS OF VARIOUS OCCUPANCIES *

OCCUPANCY	TRAVEL DISTANCE (FT.)		
	MINIMUM	MAXIMUM	AVERAGE
Theatres	40	80	63
Schools	32	108	63
Department Stores	32	176	107
Offices	50	110	83
Factories (two to four storeys)	36	125	76
Apartment Buildings	30	136	64
Hotels	48	120	76
Hospitals	40	130	76

* Extracted from *Design and Construction of Building Exits* (U.S. National Bureau of Standards).

169. It is considered that, from a practical point of view, it is more convenient to make the same requirement for maximum travel distance apply to all occupancies. In the case, however, of occupancies which involve a sleeping risk, if maximum figures are worked to, attention should be paid to such precautions as staff fire drills, smoke-stopping, and exit marking, which help to minimize the life risk involved.

TRAVEL DISTANCE IN RELATION TO CONSTRUCTION

170. We have already discussed the effect of construction on safety of life in building fires in Section 1 of this Part, and made certain recommendations affecting the structure and finishings. In connection with travel distance it is necessary to distinguish between buildings in which there may be a life risk from fire spread, and those in which any serious fire spread is unlikely on account of the construction. This involves consideration, not only of the main structure, but also of partitions and finishings.

171. Dealing first with those buildings in which the possibility of rapid fire spread due to the construction of the building may constitute a risk to life, it is apparent that the nature of partitions and surface finishes is of greater importance than that of the main structure. It is considered that if the recommendations given in Section 1 are complied with, the safe travel distance will not, in the short time interval required for evacuation, be appreciably affected by the combustibility or grade of fire resistance of the main structural elements.

172. The travel distance, then, should largely be controlled by the secondary, internal construction of buildings. The main factors involved are the combustibility and fire resistance of the partitions and the flame spread characteristics of surface finishes generally. These are the constructional factors which influence the production and spread of smoke and hot gases in the initial stages of fire, and so affect the safety of the occupants while they are using the escape routes. In general terms, a building with combustible and flame-propagating interior construction should have more closely spaced exits than a building with internal structure and finishings which are not readily affected by fire. For example, in a building with timber-stud partitions covered with combustible material, escape routes should obviously be shorter than in a building with incombustible partitions.

173. In buildings which combine a fully protected fire resisting main structure with incombustible fire resisting partitions and surface finishes having a low flame spread, the life risk from spread of fire should generally be quite small. In such cases immediate evacuation of all the occupants on the floor affected may not always be necessary, much depending then on the nature of the occupancy. It would seem reasonable also to assume that a building having an unprotected steel roof but otherwise of fully protected fire resisting construction should be treated as a fully protected building so far as travel distance is concerned. A similar argument would apply to a single-storey building constructed wholly of incombustible materials.

174. Existing codes do not all base their requirements on a variation in travel distance for different types of construction. The N.F.P.A. and New York Codes, for example, do not mention construction in connection with travel distances. There is some justification for the view that the main structure of a building does not have any considerable effect on safe travel distance, but it seems desirable to make some allowance for internal constructional features which may affect the growth of a fire in its early stages. The B.I.N.C. and Canadian Codes make a distinction between fire resisting and other types of construction. In both codes,

also, some account is taken of the nature of the secondary internal construction. The L.C.C. principles, in the case of trade and office buildings, also make a distinction between fire resisting and non-fire resisting construction, and, if a corridor is to be taken into account from a travel distance point of view, require that it should have approved fire resisting enclosures. In considering recommendations for travel distance it is necessary to treat the question of construction as a whole, so that it will be quite clear that a high travel distance figure can only apply to those buildings in which not only the main elements of structure, but also the internal partitions and surface finishes are of an adequate standard from the point of view of fire spread.

TRAVEL DISTANCE IN RELATION TO PLANNING

175. In this connection it is necessary, first, to deal with the question of the relative travel in buildings with open floor spaces compared with buildings having floor spaces subdivided into a number of rooms. The distinction depends on the stage at which warning of the fire can be expected as well as on the actual distance to be traversed. In buildings with open floor spaces it is reasonable to expect that fire will be observed in its earliest stage. In buildings where the floor areas are subdivided there is always the risk of fire starting in an unoccupied room and the accompanying danger of the corridors being heavily charged with smoke before the occupants of other rooms get warning. An example of this danger is given by the fire incident mentioned in paragraph 89 of Section 1 of this Part. It follows that a higher travel distance can be allowed across an open floor space, where the fire may be seen at once, than along a corridor serving a number of rooms.

176. Another important aspect of planning which affects safe travel distance is that of the layout of escape routes. It is obvious, for instance, that in a building with long straight corridors and a staircase at each end there can be no difficulty in finding the route to the exits, and that there is the least possible hindrance in getting to them. On the other hand, in a building where the occupants have to find their way round corners and possibly up or down short flights of stairs connecting different floor levels, it may not be at all a simple matter to reach the staircases or exits under fire conditions. These cases obviously call for special attention to such precautions as exit marking and fire drills. In this connection reference should be made to the Home Office publication *Fire Precautions in Schools*, 1945, as giving an example of the safety measures which may be desirable in special instances, with particular application in this case to boarding schools in older types of buildings.

177. An example of the danger inherent in a devious escape route is given by a recent hotel fire in an old building to which additions had been made at various times. In this incident the main staircase had no enclosure and provided a ready passage for smoke and hot gases. The guests, driven up this staircase by fire on the ground floor, made their way to a fire escape from the top floor. The route led along a corridor which was offset and had a change in level at a point where the building had been extended; thence through a bedroom to an outside fire escape. The top section of this escape was a spiral iron staircase which led to a straight iron stair, thence to a short open gangway, across an enclosed bridge, and finally down a vertical iron ladder fixed to a wall. One of the guests who lost her life must have taken a wrong turning at the top of the main staircase, for her body was found in a blind alley bedroom on the top floor. The maximum travel distance in this case, measured from the door of any bedroom to the staircase, was less than 40 ft., but it is obvious that this figure cannot be compared with a similar figure in buildings with straight corridors and enclosed staircases at either end.

178. It is difficult to regulate this effect of planning in other than a general, descriptive way. As we are concerned in this Report only with new buildings, it is not proposed to deal in detail with this aspect of the problem. It must, however, be made clear that the recommendations on travel distance made later are based on the assumption of a straightforward layout or adequate safeguards to offset any planning complexity which may make exits difficult to find. Another factor, the importance of which is emphasized by the incident quoted above, is that of travel distance from the end of a building in which staircases are placed more or less centrally and escape is therefore possible in one direction only. The problem which arises here differs from that which calls for consideration, for instance, in assembly buildings where dead-end corridors leading from the assembly area present a hazard necessitating clear signs indicating that exit is not possible. Although similar signs should be fixed in all buildings from this standpoint, we are primarily concerned here with the exit of occupants from these dead-end areas.

Recommendations on Travel Distance

179. The figures given below are based on the assumption that the layout of the building is fairly regular, or that there are adequate safeguards such as special exit marking and, where possible, fire drills to offset any complexity of planning which may make exits difficult to find. It is also assumed that the contents of the building are such that rapid fire spread would not be expected in them.

1. In buildings of fully protected fire resisting construction having partitions[1] and linings of incombustible material it is recommended that a figure of 150 ft. should be allowed, of which not more than 100 ft. should be along a corridor. Where escape is from a dead-end area this figure should be reduced to 100 ft., of which not more than 60 ft. should be along a corridor.
2. The above recommendations may apply also to buildings having an unprotected steel roof, provided the remainder of the building conforms with the conditions described and there is no combustible material in the roof or ceiling of the top floor.
3. In the case of single-storey buildings having open floor spaces and constructed wholly of incombustible materials, the maximum travel distance from any point in the building to the nearest exit should be 150 ft.
4. In buildings where the foregoing conditions are not met, the maximum travel distance should be restricted to 60 ft.

180. In measuring travel distance across an open floor space, account must be taken of the possibility that the arrangement of the contents, seating, furniture, machines, or whatever it may be, may not allow movement in a direct line. We consider that on open floor spaces travel distance should always be measured along rectangular and not diagonal paths. Travel distance should be measured from the top step of a staircase to the farthest point of that part of the building which is under consideration. (*Note.*—For illustrations of these recommendations for dead-end areas, see Figures 8 and 9.)

MINIMUM NUMBER OF EXITS

BUILDINGS OTHER THAN ASSEMBLY BUILDINGS

181. As provision of alternative means of escape is one of the major factors safeguarding life in the event of a fire in a building, it follows that the minimum number of exits in any building should normally be two. As an exception to this

[1] For construction of corridor partitions see paragraphs 287-293.

general rule it may be noted that in rooms, floor areas or buildings of restricted size a requirement that two staircases or exits should be provided may be onerous and in such circumstances one staircase or exit should be permissible, it being understood that alternative egress can be made through windows, if necessary with the assistance of the fire service. The limitations necessary for rooms or floor areas having only one exit are discussed in paragraphs 184-185 and for single staircase buildings in paragraphs 190-211. Apart, however, from these exceptions all rooms, floor areas or buildings should be provided with two or more staircases or exits.

182. In high multi-stair buildings the requisite number of staircases will largely be determined by the number of occupants and the desired width of staircase. In paragraph 255 *et seq.* the subject of staircase width is fully discussed, and recommendations are made for the discharge values which may be credited to staircases of various widths and heights. Having first calculated the total number of occupants of a building it will thus be a simple matter to determine how many staircases of any desired width will be required. Alternatively, if planning considerations lead to a prior determination of the number of staircases which is desired the width necessary for that number of staircases may similarly be obtained. Should the calculated widths be excessive one or more additional staircases will be required. In either case, care must be taken to ensure that the maximum travel distances recommended in paragraph 179 are not exceeded.

183. In low buildings staircase widths and number of occupants will frequently not be the major factor in determining the minimum number of staircases, as it will be found that staircases calculated on such a basis will often be so few in number that the recommended maximum travel distances will be greatly exceeded. In such cases it will be necessary first to locate the staircases having regard to maximum travel distances and general planning considerations and later to check the adequacy of number and width for the number of occupants.

184. The detailed discussion of single staircase buildings in paragraphs 190-211 relates to the building as a whole. Apart from the restrictions placed upon such buildings it will be desirable also to limit the number of occupants of a single room or of a floor area at ground or higher levels having only one exit. In Table 6 the maximum recommended floor areas for single staircase buildings vary from 4000 sq. ft. in fully-protected construction to 1000 sq. ft. in Type 5 construction. At ground level the construction of a building is of less significance from the point of view of escape than at higher levels, particularly having regard to the possibility of escape through windows. It would appear reasonable therefore to adopt the maximum figure of 4000 sq. ft. mentioned above as the maximum permissible floor area at ground level having only one exit, regardless of the type of construction of the building.

185. The maximum total number of occupants permitted in a single staircase building of fully protected construction is 250. It might perhaps appear equally reasonable to adopt this figure as the maximum number of occupants to be permitted in a single room or on a floor area having only one exit. It should be appreciated, however, that the occupants will normally be distributed over a number of floors so that on any one floor the number of persons will be a fraction of 250. This distribution of occupants over a number of floors results in a greater degree of personal safety than would be the case if they were concentrated on one floor. It would seem advisable therefore to impose some limitation on the number of persons which may be permitted both on the upper floors of a single staircase building and on a floor area at ground level or in a single room having only one exit. In the Canadian Code not more than 100 persons are permitted in a room having only one doorway or on a ground floor area having only one exit. Other

American codes permit a similar number, or even less. It is suggested that a maximum number of 100 persons would be a reasonable figure to adopt. It is recommended, therefore, that any room or floor area which is designed to accommodate more than 100 persons or any floor area which exceeds 4000 sq. ft. should have at least two independent exits. This assumes, of course, that surface finishes for various occupancies conform with the recommendations in Section 1 of this Part.

ASSEMBLY BUILDINGS

186. The question of the number and distribution of exits in assembly buildings [1] has already been discussed briefly in dealing with travel distance (paragraph 163). It was suggested there that in this type of occupancy the primary factor involved is not travel distance, as is the case in other types of buildings, but the dispersal of the people to a sufficient number of exits to avoid having an unduly large number crowded round any one exit, however wide. Although it would be possible to calculate a minimum number of exits by applying the general travel distance recommendations of paragraph 179, it would generally be found that the number would be insufficient to fulfil the above condition. It is necessary, therefore, to regulate the minimum number of exits by a requirement which is directly related to the number of persons involved. This way of dealing with the subject is that generally followed by existing codes and Table 5 gives a summary of the requirements of a number of these codes, and also our recommendations for the maximum population which can be allowed in buildings with up to five exits. It is considered that where the number of people exceeds 1700 on any floor space or balcony, each building should be considered on its merits.

TABLE 5. NUMBER OF EXITS IN ASSEMBLY BUILDINGS IN RELATION TO POPULATION

NAME OF CODE	MAXIMUM NUMBER OF PEOPLE ON ONE FLOOR SPACE OR BALCONY			
B.I.N.C. (at 100 persons per unit)	600	1000	1400	1800
H.O. Manual (at 100 persons per unit)	500	900	1300	1700
L.C.C.	500	750	1000	1250
New York	900	1800	over 1800	—
Canadian and N.F.P.A.	600	1000	over 1000	—
Recommendation [2]	600	1000	1400	1700
Minimum number of exits	2	3	4	5

LOCATION OF EXITS

187. A layout which satisfies requirements with regard to number of exits may still be undesirable from the point of view of life safety because of faulty exit location. For example, a long narrow room used as an assembly hall and having two exits might have both exits at one end and quite close together. A fire at that end might then make it dangerous to use either exit. The general principle

[1] We are here concerned only with the building. It is essential that the street doors of an assembly building should discharge on to streets or other spaces sufficiently wide to ensure that flow from the building is not hindered. In addition, the discharge should be distributed over more than one street according to the number of persons assembled.

[2] For exit width see paragraphs 246-247 and Table 8.

involved is simply that the required number of exits should be distributed at points as widely separated as practical planning considerations will allow. The exigencies of planning must not, of course, be taken to justify conditions such as in the example given above; in other words, satisfactory provision for alternative egress must be made in every case.

188. Despite the fact that this general principle is quite simple and obvious, it is by no means always adequately observed in practice. A recent fire in an office building illustrates the point. The original part of this building had a staircase adjoining the rear wall. An extension was later added on that side and provided with its own staircase, which, however, was located adjacent to the original stair, and separated from it only by the width of a narrow light well. The two stairs were connected by a short corridor at each floor level, and as neither was enclosed, any fire which cut off one was practically certain to make both useless as escape routes. Finally, an additional fire escape stair had been added, and the place chosen for this was, significantly, the light well between the two main staircases. In effect, the three stairs crowded together, presumably for planning convenience, were of little more value than one from the point of view of life safety in fire.

189. It is difficult to regulate the location of exits by formula. The operation of the travel distance requirement does, to a certain extent, control their distribution. In particular instances an arbitrary restriction of travel distance to a figure less than that required from the point of view of circulation under fire conditions and of passage through smoke, might be used to ensure satisfactory distribution of exits. This indirect method, however, besides having no rational basis, is liable to interfere unnecessarily with the designer's freedom in planning a building. An example of a direct method of controlling exit location is seen in the requirement of the Pacific Coast Code that in assembly buildings with a working stage and accommodation for 1000 or more persons in one room, there should be at least one exit on each of three sides of the room. It is obvious that, in a long, narrow assembly space, this condition might be complied with, and yet the distribution of exits be entirely unsatisfactory. It is considered that this question is essentially one in which judgment and experience must be used to ensure that in each individual building the exits will be distributed in such a way as to provide satisfactorily for alternative egress.

LIMITATION OF SIZE AND OCCUPANCY OF SINGLE-STAIRCASE BUILDINGS

190. Single-staircase buildings receive considerable attention in existing codes. It is generally recognized that, ideally, every part of a building should have two entirely independent escape routes. In practice, however, a considerable proportion of smaller buildings have only a single staircase, and if that is blocked in the early stages of a fire, say by smoke, rescue by the fire service may be the only alternative method of escape. It is desirable to limit the size and occupancy of buildings in which this condition is permitted on account of three factors:

1. There should not be an excessive number of people involved.
2. Rescue might not be possible owing to excessive height or difficulty of approach.
3. It should not be necessary to use emergency rescue methods with such people as bed-ridden patients.

Whether or not prompt attendance of the fire service can be expected has also an important bearing on the subject. This has to be considered particularly in connection with the height of buildings which are not within easy reach of a fire station permanently manned and suitably equipped for rescue work.

FIRE GRADING OF BUILDINGS

191. It is convenient to consider under four headings the limitations which should be applied to single-staircase buildings. These are:

1. Occupancy.
2. Height.
3. Floor area.
4. Number of occupants.

Table 6 indicates the limitations imposed by existing codes in respect of these four factors, and the extent to which they are varied on account of differences in construction type, and also on account of certain safety measures, such as roof exits, which are required in particular cases.

LIMITATION OF OCCUPANCY

192. Two of the three factors mentioned in paragraph 190 indicate limitations of occupancy that are desirable in single-staircase buildings. The fact that it is desirable to avoid having any large number of people involved indicates that assembly occupancies should be excluded, and the difficulty of rescue work with infirm people or invalids excludes institutional buildings. This means that single-staircase buildings would be restricted to trade and commercial occupancies and to residential buildings of a non-institutional type, *e.g.* flats. This limitation of occupancy is generally in accordance with existing code requirements. It is of interest that the New York Code restricts occupancy by setting a limit of population density for single-staircase buildings more than two storeys high. The population density must not exceed one person per 50 sq. ft. of floor area, which, in effect, excludes assembly occupancies.

LIMITATION OF HEIGHT[1]

193. The height limitation for single-staircase buildings depends essentially on the nature of the rescue appliances which will be immediately available on the outbreak of fire. In areas where suitable turntable ladder appliances are available within easy range, rescue operations can be successfully carried out at heights up to nearly 100 ft. These appliances are not, however, primarily intended for rescue work, the number available is limited, and in any case it is undesirable that rescue should be relied on as a means of escape in buildings of such great height.

194. An illustration of the disastrous results which may follow when rescue is impossible because of the height of a building, is afforded by the fire in 1946 at the Winecoff Hotel, Atlanta, when 119 lives were lost. In that building, which was fifteen storeys high, a single central staircase was provided and this was lined throughout with inflammable materials which were the primary cause of the disaster. If this condition were excluded and the staircase were constructed wholly of incombustible material and properly cut off from the rest of the building, it might be contended that rescue work would be on a small scale and reliance could safely be placed on a turntable ladder for rescue up to a height of, say, 90 ft. This might well be the case if, as actually happened in one or two rooms of the Winecoff Hotel, occupants were awake and could be relied on to make full use of the fire resisting character of the building. But the risks of fire spreading into rooms from windows of lower storeys, and of leakage of smoke and hot gases through cracks or doors left open, present dangers which cannot adequately be guarded against, except by the provision of alternative means of escape independent of the main staircase.

[1] In this Section, height is measured to top floor level.

195. The possibility of rescue by the fire service will generally, of course, only apply in towns. In rural districts the immediate attendance of the fire service cannot normally be expected (see Part II, paragraph 8), and improvised rescue methods may be necessary. In these circumstances the maximum height of buildings should naturally be much less.

196. The height allowed for single-staircase buildings in existing codes varies considerably. The New York Code allows a height of 75 ft., and this may be exceeded in the case of buildings of incombustible fire resisting construction with the staircase arranged in the form of a fire tower. In London, on the other hand, the normal height limitation is 42 ft. to the top floor. In this case, however, two additional floors are allowed in trade and office buildings where there are the added safeguards of a roof exit with access to an adjoining roof, and a fire resisting screen cutting off the flights of stairs above the 42 ft. level from the rest of the staircase. The B.I.N.C. Code gives a height to top floor of 47 ft., but only allows one floor above this level when there is a roof exit and cut-off screen. This figure applies to buildings which are within two and a half miles of a fire station with a permanently manned 50 ft. escape or turntable ladder, *i.e.* in urban areas. When this condition is not fulfilled, single-staircase buildings are required to have alternative means of escape from all floors at a greater height than 20 ft. The Canadian Code restricts single-staircase buildings to a height of three storeys in fire resisting construction and two storeys otherwise. The N.F.P.A. Code only allows a height of two storeys. The requirements of these two Codes, not being limited in application to large urban areas, are presumably based on rescue conditions which may arise in places where an immediate fire service turnout cannot be expected.

197. In considering this question in relation to buildings in urban areas, the main factor to be taken into account is the type of rescue appliance which will most commonly be available. In this country the wheeled escape is the principal rescue appliance of the fire service, and the height limit for single-staircase buildings must be fixed within the normal working range of this appliance. From information supplied by the fire service it appears that the length when fully extended of the types of wheeled escape in most common use varies from 48 ft. 6 in. to 54 ft. 6 in. Taking into account the number of appliances of the various individual types which are at present in service, it is considered by the fire service that, for the present purpose, calculations should be based on a 50 ft. escape. It is not, at present, possible to foresee any large-scale adoption of the longer escapes of which examples have, in the past, been manufactured for certain local fire brigades. The use of these escapes introduces problems of manning and stability which make it improbable that they will be adopted universally in the near future. In addition, the physical difficulties of rescue from heights greater than that reached by the 50 ft. escape have to be considered.

198. When the 50 ft. escape is working at the most convenient angle, which is about 70°, the vertical height to the top of the ladder is 47 ft. In fixing the highest floor level from which rescue should normally be considered possible with this height of reach, it is desirable to allow for the ladder projecting a short distance above window-sill level to provide a handhold for the firemen. Allowing 2 ft. for this purpose and a 3 ft. height from floor level to window sill, the appropriate height to the floor would be 42 ft. (see Part II, Fig. 1).

199. It may be noted here that in order to facilitate rescue in emergency there should be a reasonable number of windows on each floor above the ground floor facing a street or open space, the opening portion of which is sufficiently large (not less than 2 ft. 9 in. by 1 ft. 3 in. wide in the clear when the sash is open) to permit the passage of a full-grown person. This recommendation should apply

to all buildings and not only to the single-staircase buildings which we are considering at this stage.

200. It must, of course, be realized that the fixing of a limit of 42 ft. does not mean that wheeled escapes cannot be used for rescue work from greater heights. The appliances themselves vary appreciably in length, and an extension beyond the normal operating limit can be obtained in emergency. It is also possible in extreme necessity to use portable extension ladders to increase still further the height that can be reached. These factors, however, must obviously be discounted in thinking of the use of the appliance for normal rescue purposes. Although there have been many rescues from heights beyond the normal working limit of the wheeled escape, these should be regarded as instances caused by deficiency in the structural means of escape. They cannot be treated as evidence that rescue from these heights should be regarded as an accepted procedure.

201. We recommend therefore that in urban areas, or in districts where early attendance of the fire service can be relied upon, the height of single-staircase buildings should generally not exceed 42 ft. An exception may be made, however, where there is no sleeping risk and the building is of fully protected fire resisting construction. In such cases the height may be increased to 60 ft. if the additional precaution is provided of a cut-off screen in the staircase separating the portion above 42 ft. high from the portion below, and there is a roof exit giving safe access to the ground. Any single-staircase building of greater height than the above should be provided with secondary means of escape, independent of the staircase, from all floors above 42 ft. high. This condition would be satisfied by a horizontal exit (see paragraphs 283-284) or by an escape stair to a roof from which there is safe access to the ground.

202. In areas where prompt attendance of the fire service cannot be expected, the height of single-staircase buildings should be limited to 20 ft. unless secondary means of escape, independent of the staircase, is provided.

203. If a single staircase is usable in a downward direction only, *i.e.* if there is no roof exit, it should be doubly protected where access doorways are formed in the staircase enclosure. This may be achieved in the case of an open floor by means of a lobby at the stair entry provided with inner and outer self-closing fire-check doors, or in the case of a subdivided floor by the provision of self-closing fire-check doors to all rooms entered off the corridor and one similar door (or pair of doors) in the staircase enclosure. This provision, which is termed "lobby approach" or "corridor approach," would not be required on the top floor of any building.

204. The effect of adding a basement to a single-staircase building is to increase the danger that the staircase may be rendered unusable through attack by smoke or flame. As a measure of safety, therefore, it is recommended that all floors below ground should be cut off from the staircase either by "lobby approach" or by a fire resisting screen with self-closing fire-check doors separating the staircase below ground from the remainder. In addition separate means of escape, independent of the staircase, should be provided from all floors below ground where persons are employed. Such means of escape should be properly separated from the ground floor and any intermediate storey below.

LIMITATION OF FLOOR AREA

205. The limitation of floor area has to be considered in relation to construction. In a fully protected fire resisting building only the floor on which fire originated would normally be affected immediately, and the extent of the rescue work

necessary would be correspondingly limited. On the other hand, in a building with floors having less than, say, Grade E (half-hour) fire resistance, several storeys might rapidly be involved, and if the staircase became impassable in the early stages of a fire, rescue operations might be required on a much larger scale.

206. Existing codes, with the exception of the L.C.C. Code, do not give much attention to this question of construction in relation to the permissible floor area of single-staircase buildings. The L.C.C. Code for trade and office buildings [1] with one staircase restricts floor area to 1000 sq. ft. in buildings with timber floors and plaster or other suitable ceilings, but, if the floors, are of incombustible construction, it allows an increase in floor area to 2000 sq. ft., or in certain cases, 3500 sq. ft. In the case of residential flats the L.C.C. Code accepts a single staircase if there are not more than four flats on each floor, and there is no floor more than 42 ft. above ground. If, however, the floors are of fire resisting materials there may be six flats on each floor provided the corridors are fire separated from the staircase. This number of flats would generally require a greater floor area than the figures given above which apply to trade and office buildings. It must be remembered, of course, that there is generally a higher standard of fire resistance in the separation between flats than, say, between individual offices in an office building.

207. The B.I.N.C. Code recommends area limitation in certain occupancies in terms of the total floor area above first floor or 20 ft. from ground, *i.e.* above a height beyond which special rescue appliances become necessary. In the case of factories and warehouses with a single staircase, the total floor area above the first floor or 20 ft. from ground level is limited to 1000 sq. ft. In hotels the total floor area above 20 ft. from ground level is limited to 2000 sq. ft. The New York Code allows a floor area of 2500 sq. ft. in single-staircase buildings, but in the case of buildings two storeys high with the upper floor not more than 17 ft. above ground, a floor area of 4000 sq. ft. is allowed. In the Canadian Code the permissible floor area is 2000 sq. ft., but a figure of 6000 sq. ft. is allowed for some commercial and industrial occupancies in buildings of fire resisting construction which are sprinklered. Sprinklers are not, however, required by this Code in office buildings.

208. We recommend that in single-staircase buildings where the floors and other main structural elements do not attain any specified grade of fire resistance, the floor area should be limited to 1000 sq. ft. In buildings of Type 4 construction (minimum fire resistance Grade E—half an hour) the floor area could be increased to 2500 sq. ft. Where fully protected construction is used floor areas up to 4000 sq. ft. could be adopted except in buildings between 42 ft. and 60 ft. high where, if secondary means of escape from floors above 42 ft. high is not provided, the area should be limited to 2500 sq. ft. (see Table 6). These figures would apply to occupancies in which no special hazard is involved. In the case of hazardous occupancies such as factories using highly inflammable materials, each building should be considered on its merits, taking into account any special fire precautions which are considered necessary. Areas should be measured at the level of the first floor above ground.

LIMITATION OF TOTAL POPULATION

209. The figures given in the foregoing paragraphs might in some cases allow a very considerable population in buildings with only one staircase, a condition which has to be considered carefully. Take the case of a building of Type 3 construction, with a floor area of 4000 sq. ft. and a height to top floor of 42 ft. This building might have four floors above the ground floor, and if the population density were

[1] *Means of Escape in Case of Fire.*

one person per 50 sq. ft., the total population would be 320. Whilst it is unlikely that more than a fraction of the people would require to be rescued, the possibility remains that the fire service might be faced with a rescue problem of considerable magnitude. A limitation of total population seems therefore to be desirable. This question is mentioned in the L.C.C. and B.I.N.C. Codes. It is understood, however, that the limitation in the former is primarily based on considerations of staircase width. In trade and office buildings, the total number of people on floors above the ground floor is limited to 300 when the population is distributed and 250 when the population is principally on one floor. It should be noted, however, that in buildings with timber floors, the limitation of height and floor area would make it virtually impossible to reach these figures. In block dwellings with balcony access to a single staircase the number of persons on floors above the ground storey is limited to 150. The B.I.N.C. Code, in the case of factories and warehouses, limits the number of people above the first floor or 20 ft. from ground level, to twenty.

210. In this connection also it is desirable to make a distinction between buildings of fully protected fire resisting construction and those of other types of construction in which there is a greater danger from fire spread. It is reasonable therefore that in fully protected buildings the total population should be greater than in buildings which are not fully protected. It is recommended that, in single-staircase buildings where there are floors or other main structural elements with a fire resistance of less than half an hour, the total population above the ground storey should not exceed fifty. In buildings of Type 4 construction (minimum fire resistance half an hour) a total population up to 150 could be allowed and in buildings of fully protected fire resisting construction a maximum total population of 250 is recommended.

Summary of Recommendations for Single-Staircase Buildings

211. The foregoing recommendations for single-staircase buildings are set out in Table 6 and illustrated in Figures 4-9. Table 6 also sets out the requirements of the Codes quoted.

TABLE 6.

Table 6. Comparison of Code Restrictions on Single-Staircase Buildings, with Recommendations

Code	Occupancy	Construction	Additional safeguards	Maximum height to top floor level	Maximum floor area at first floor level	Maximum total population on floors above ground floor
L.C.C.	Trade or office	Timber floors and plaster ceilings	Roof exit or "lobby approach" to stairs	42 ft.	1000 sq. ft.	300 where people are distributed 250 where people are mostly on one floor
			Cut-off screen in stair, and roof exit	Two floors above 42 ft. height		
			Alternative means of escape independent of main stair from floors above 42 ft. and "lobby approach" below 42 ft.	No restriction up to 100 ft. but subject to town planning or building act requirements		
		Incombustible floors	Roof exit or "lobby approach" to stairs	42 ft.	3500 sq. ft.	
			Cut-off screen in stair and roof exit	Two floors above 42 ft. height	2000 sq. ft.	
			Alternative means of escape independent of main stair from floors above 42 ft. and "lobby approach" below 42 ft.	No restriction up to 100 ft. but subject to town planning or building act requirements	3500 sq. ft.	
	Residential flats	Not specified	"Lobby approach" to stairs	42 ft.	Four flats on each floor	Not specified
			Alternative means of escape independent of main stair from flats on floors above 42 ft.	No restriction up to 100 ft. but subject to town planning or building act requirements		

TABLE 6 (*contd.*). COMPARISON OF CODE RESTRICTIONS ON SINGLE-STAIRCASE BUILDINGS, WITH RECOMMENDATIONS

CODE	OCCUPANCY	CONSTRUCTION	ADDITIONAL SAFEGUARDS	MAXIMUM HEIGHT TO TOP FLOOR LEVEL	MAXIMUM FLOOR AREA AT FIRST FLOOR LEVEL	MAXIMUM TOTAL POPULATION ON FLOORS ABOVE GROUND FLOOR
L.C.C.—*contd.*	Residential Flats—*contd.*	Floors of fire resisting materials	Corridors separated by fire resisting screen from stair	42 ft.	Six flats on each floor	Not specified
			Alternative means of escape independent of main stair from flats on floors above 42 ft.	No restriction up to 100 ft. but subject to town planning or building act requirements		
	Block dwellings with balcony access	Not specified		42 ft.	Not specified	150 on floors above ground storey
			Access from top floor to balcony below or adjacent	One floor above 42 ft. height		
B.I.N.C. (see Note 1)	Offices, mansion flats and block dwellings		Roof exit	47 ft.		
			Cut-off screen in stair, and roof exit	One floor above 47 ft. height		
	Factories and warehouses				Total floor area above 1st floor or 20 ft. from ground 1000 sq. ft.	Twenty people above 1st floor or 20 ft. from ground
	Hotels				Total floor area above 20 ft. from ground 2000 sq. ft.	
New York		Incombustible fire resisting	Stair in form of a fire tower	Height over 75 ft.	2500 sq. ft.	
	Population density not exceeding one person per 50 sq. ft.	Not specified		75 ft.		
		Not specified	Travel distance not to exceed 100 ft.	17 ft. (two storeys)	4000 sq. ft.	

TABLE 6 (*contd.*). COMPARISON OF CODE RESTRICTIONS ON SINGLE-STAIRCASE BUILDINGS, WITH RECOMMENDATIONS

CODE	OCCUPANCY	CONSTRUCTION	ADDITIONAL SAFEGUARDS	MAXIMUM HEIGHT TO TOP FLOOR LEVEL	MAXIMUM FLOOR AREA AT FIRST FLOOR LEVEL	MAXIMUM TOTAL POPULATION ON FLOORS ABOVE GROUND FLOOR
Canadian	Commercial and industrial with no exceptional hazard	Incombustible fire resisting. Minimum fire resistance 1 hr.		Three storeys	3000 sq. ft.	
		Any type		Two storeys		
		Incombustible fire resisting. Minimum resistance 1 hr.	Building sprinklered throughout except in case of offices		6000 sq. ft.	
	Residential including residential schools, convents, hotels, multiple dwellings	Incombustible fire resisting. Minimum fire resistance 1 hr.		Three storeys	3000 sq. ft.	
N.F.P.A.	Hotels and apartment houses	Not specified	Enclosed and protected stair	Two storeys	3200 sq. ft.	
Recommendations for urban areas or districts where prompt attendance of the fire service can be expected	Trade, Commercial and Industrial Buildings (excluding abnormal hazards)	Types 1-3 (see Note 2)	(a) Roof exit, or, where roof exit cannot be provided, "lobby approach" from all floors below top floor	42 ft.	4000 sq. ft.	250
			(b) Roof exit with cut-off screen separating staircase to floors above 42 ft. high from staircase to floors below	60 ft.	2500 sq. ft.	250
			(c) "Lobby approach" from all floors below 42 ft. height and alternative means of escape independent of the main staircase from all floors above 42 ft. height	No limitation	4000 sq. ft.	250

TABLE 6 (*contd.*). COMPARISON OF CODE RESTRICTIONS ON SINGLE-STAIRCASE BUILDINGS, WITH RECOMMENDATIONS

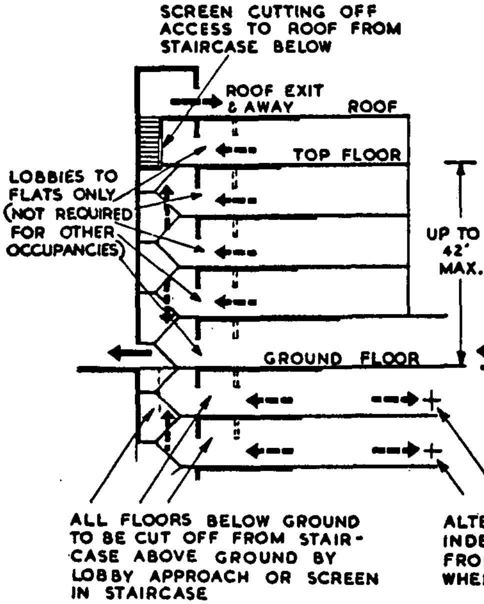
CODE	OCCUPANCY	CONSTRUCTION	ADDITIONAL SAFEGUARDS	MAXIMUM HEIGHT TO TOP FLOOR LEVEL	MAXIMUM FLOOR AREA AT FIRST FLOOR LEVEL	MAXIMUM TOTAL POPULATION ON FLOORS ABOVE GROUND FLOOR
Recommendations for urban areas or districts where prompt attendance of the fire service can be expected—*contd.*	Trade, etc., buildings—*contd.*	Type 4	(d) as (a) above	42 ft.	2500 sq. ft.	150
		Type 5	(e) as (a) above	42 ft.	1000 sq. ft.	50
	Hotels and similar-occupancies with sleeping risks	Types 1-3	(f) as (a) above	42 ft.	4000 sq. ft.	250
			(g) as (c) above	No limitation		
		Type 4	(h) as (a) above	42 ft.	2500 sq. ft.	150
		Types 1-3	(i) "Lobby approach" from each flat (see Note 3)	42 ft.	Four flats per floor, 4000 sq. ft.	
		Type 4	(j) "Lobby approach" from each flat (see Note 3)	42 ft.	Four flats per floor, 2500 sq. ft.	
	Flats (see Note 4)	Types 1-3	(k) "Lobby approach" from each flat (see Note 3), alternative means of escape independent of the main staircase from all flats above 42 ft. height	No limitation	Four flats per floor, 4000 sq. ft.	

Notes. 1. In buildings which are not within two and a half miles of a fire station having a permanently manned rescue appliance, alternative means of escape are required from all floors at a greater height than 20 ft.

2. For explanation of construction types see Part I of this Report (*Post-War Building Studies No.* 20), paragraphs 56-75, and Appendix IV of this volume.

3. In the case of flats the hall of the flat will serve as the "lobby" and only the entrance door between the hall and staircase need be of a self-closing fire-check type.

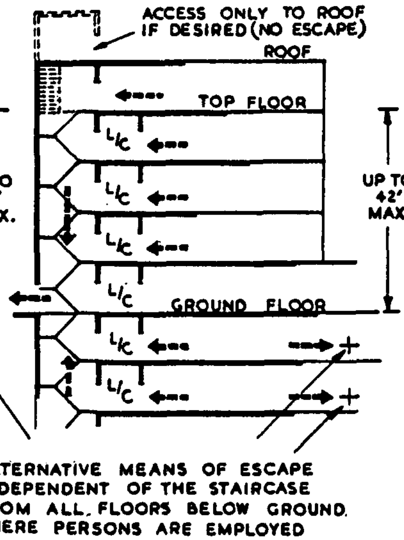
4. Not applicable to blocks of flats approached by external balconies.



SECTION

FIG. 4

WITH ROOF EXIT



SECTION

FIG. 5

WITHOUT ROOF EXIT

L-C indicates " Lobby " or " Corridor Approach "—see para. 203 and Figs. 8 and 9.

In the case of flats the hall of each flat will serve as a " lobby."

In buildings of single occupancy the roof exit may be approached through a room, provided the room is cut off from the staircase by a self-closing fire-check door.

OCCUPANCY	TYPE OF CONSTRUCTION	MAXIMUM FLOOR AREA ON ANY ONE FLOOR ABOVE GROUND FLOOR	MAXIMUM TOTAL POPULATION ABOVE GROUND FLOOR
Not involving sleeping or abnormal risks	1, 2 and 3	4,000 sq. ft.	250
	4	2,500 sq. ft.	150
	5	1,000 sq. ft.	50
Involving sleeping risks*	1, 2 and 3	4,000 sq. ft. or 4 Flats	250
	4	2,500 sq. ft. or 4 Flats	150

* Not applicable to blocks of flats approached by external balconies.

FIGS. 4 and 5

SINGLE-STAIRCASE BUILDINGS NOT HIGHER THAN 42 FT. TO TOP-FLOOR LEVEL

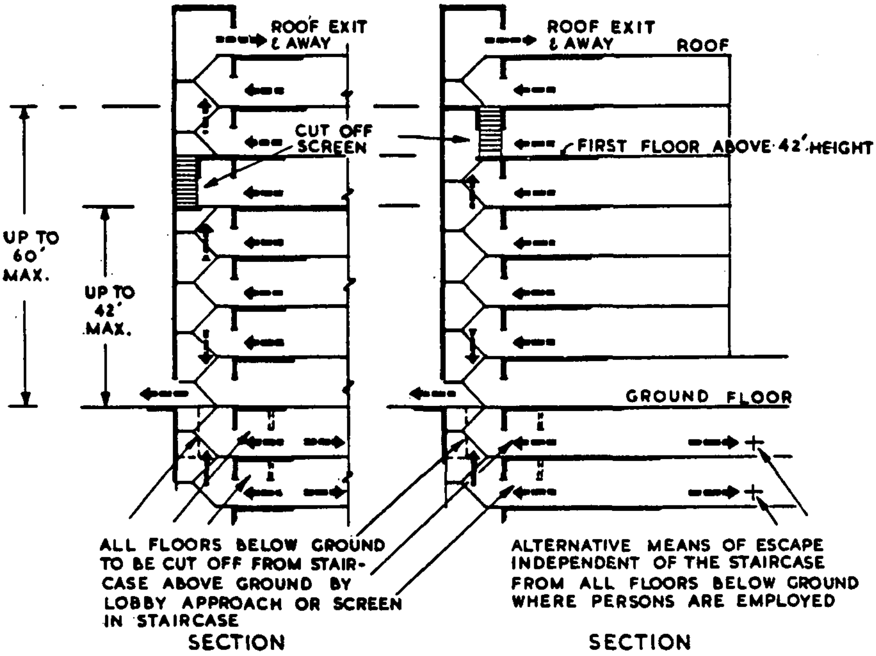


FIG. 6A

SCREEN BELOW LEVEL OF FIRST FLOOR ABOVE 42 FT. HEIGHT

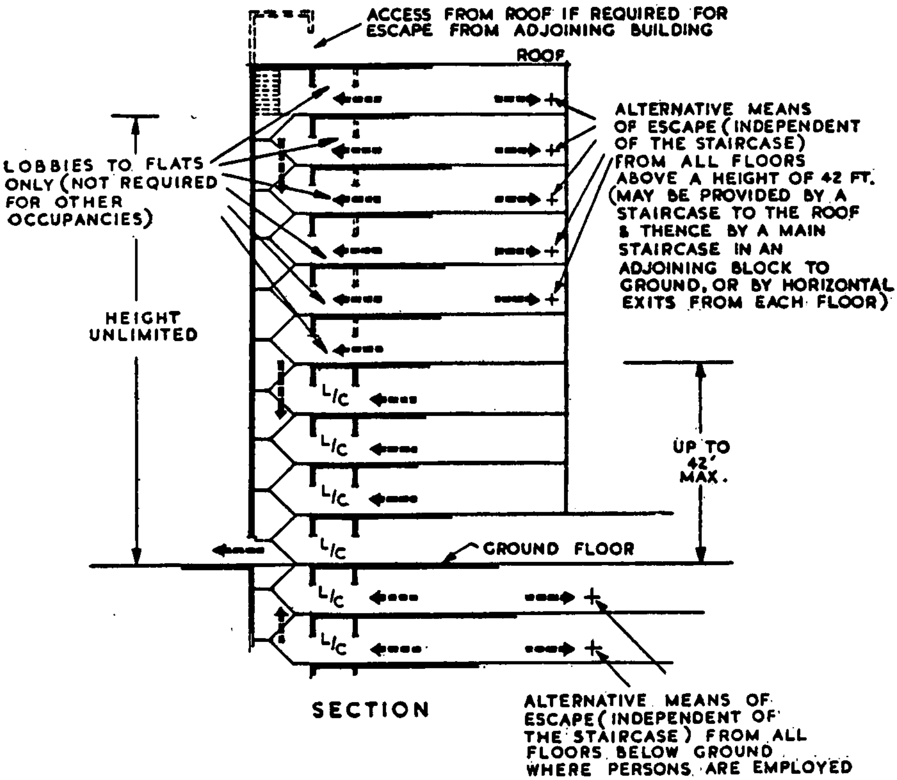
FIG. 6B

SCREEN ABOVE LEVEL OF FIRST FLOOR ABOVE 42 FT. HEIGHT

OCCUPANCY	TYPE OF CONSTRUCTION	MAXIMUM FLOOR AREA OF ANY ONE FLOOR ABOVE GROUND FLOOR	MAXIMUM TOTAL POPULATION ABOVE GROUND FLOOR
Not involving sleeping or abnormal risks	1, 2 and 3	2,500 sq. ft.	250

FIGS. 6A and 6B

SINGLE-STAIRCASE BUILDINGS NOT HIGHER THAN 60 FT. TO TOP-FLOOR LEVEL—ALTERNATIVE POSITIONS FOR CUT-OFF SCREEN SEPARATING STAIRCASE TO FLOORS ABOVE 42 FT. HEIGHT FROM STAIRCASE BELOW



L-C indicates "Lobby" or "Corridor Approach"—see para. 203.
In the case of flats the hall of each flat will serve as a "lobby."

OCCUPANCY	TYPE OF CONSTRUCTION	MAXIMUM FLOOR AREA ON ANY ONE FLOOR ABOVE GROUND FLOOR	MAXIMUM TOTAL POPULATION ABOVE GROUND FLOOR
With or without sleeping risks but not involving abnormal risks	1, 2 and 3	4,000 sq. ft. or 4 Flats*	250

* Not applicable to blocks of flats approached by external balconies.

FIG. 7

SINGLE-STAIRCASE BUILDINGS OF UNLIMITED HEIGHT

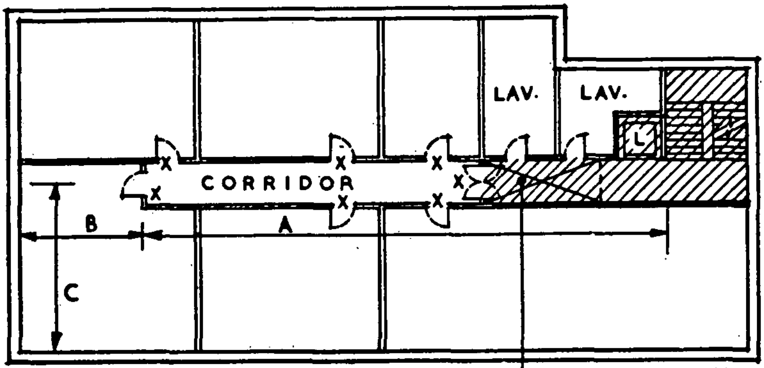


FIG. 8

SUB-DIVIDED FLOOR

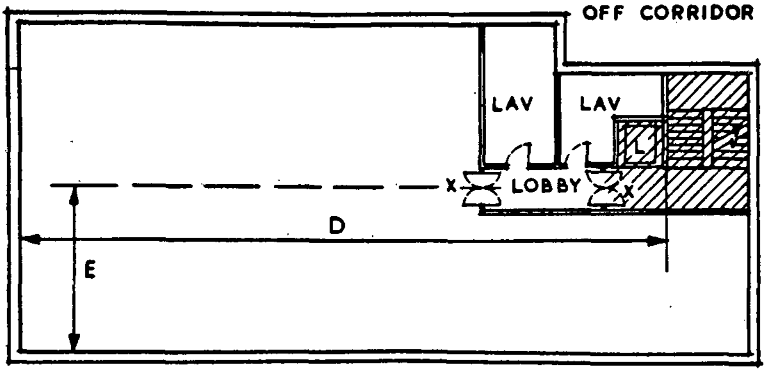


FIG. 9

OPEN FLOOR

Area shown hatched to be bounded by partitions having the grade of fire resistance required for vertical shafts—see Part 1 of Report, Paras. 143 and 144.

No rooms other than lavatories may open out of this area.

" X " indicates self-closing fire-check doors which should be provided to all doors other than lavatory doors opening out of the lobby or corridor. (If the corridor is itself cut off from the staircase by a lobby, self-closing fire-check doors are not necessary to rooms opening out of corridor.)

MAXIMUM TRAVEL DISTANCES		
DIMENSION	TYPE OF CONSTRUCTION	
	1, 2 and 3	4 and 5
A	60 ft.	—
A+B+C	100 ft.	60 ft.
D+E	100 ft.	60 ft.

FIGS. 8 and 9

LOBBY APPROACH AND CORRIDOR APPROACH IN SINGLE-STAIRCASE BUILDINGS AND MAXIMUM TRAVEL DISTANCES FOR DEAD-END AREAS

PRECAUTIONS RELATING TO PERSONAL SAFETY

EXIT WIDTH

212. We have already seen that in fixing the number and position of stairs and other exits, the architect's sense of proportion and experience of circulation problems in buildings can generally be relied on to produce a satisfactory arrangement. This also applies in the matter of exit width. The architect is, however, also guided and controlled by code requirements, and there have been cases where these requirements were considered unduly onerous. A completely satisfactory and rational treatment of the problem has not yet been achieved. It seems unlikely that, in a subject of this nature, which deals with the movement of people under widely varying conditions, a solution can be reached which will preclude all difference of opinion. Some experimental data are, however, available, and certain principles have been developed which indicate the lines along which the problem can be approached. In the following pages the present methods of calculating exit width are examined, and some consideration given to the question of the measurement of width in units. Later, a method of calculating staircase width is discussed. The term "unit width" signifies the width occupied by persons moving in single file.

EXPERIMENTAL DATA ON MOVEMENT OF PEOPLE IN EXITS

213. The question of traffic movement in exits has been the subject of investigation and test at various times both in this country and abroad. Only a limited number of tests have been made in this country. Figures for eight tests have been published in Appendices to the Factories Act, 1937.[1] More extensive tests have been made in America, notably by the U.S. Bureau of Standards, the results of which are presented in their publication *Design and Construction of Building Exits* (1935). These tests have, with one or two exceptions, been carried out under random flow conditions, *i.e.* in the course of normal use of the buildings where the tests were made, or during fire drills. The observations were, of course, made whilst the exits were being used to capacity as far as could be judged. It is useful to compare these tests with the results of experiments carried out by the Paris Fire Brigade with firemen under controlled conditions. These results, published in 1938 and 1945, help to isolate the effect of certain factors which have an influence on the rate of movement in exits.

214. For the purpose of comparison the figures for these various tests have been set down in a uniform fashion in Appendix I. It should be noted that, for this purpose, a 21 in. unit of width has been adopted except where otherwise mentioned, and fractions of units have been considered of proportionate value. If only complete units had been considered effective, higher values of the discharge per unit would have resulted in many cases. For example, if a 4 ft. wide stair discharges 96 persons per minute, the number per unit width per minute, taking the full width as effective, would be $96\times\frac{21}{48}=42$. If, however, the stair were considered to be only two units wide, the number per unit width per minute would be $\frac{96}{2}=48$.

215. The results given in Appendix I show a disconcertingly wide variation. The rate of movement on stairs varies between 19 and 107 persons per unit width per minute. The extreme figures can be readily discounted for practical purposes, but there still remains a considerable variation to be taken into account in fixing a reasonable figure for use in determining means of escape requirements. Consideration of the test results and the available explanatory notes indicates that the

[1] Factories Act, 1937. *Means of Escape in Case of Fire : Memorandum for the Guidance of Local Authorities as to the granting of Certificates under Section* 34 *of the Act.*

features of traffic movement phenomena in which variation can occur may be considered under four heads:

1. Urgency motive controlling speed of movement.
2. Pressure and flow from waiting crowd.
3. Relative effectiveness of wide and narrow exits.
4. Other characteristics.

URGENCY MOTIVE CONTROLLING SPEED OF MOVEMENT

216. It is obvious from the results of the French tests that the urgency motive is a main factor causing a variation in the rate of discharge. It will be noted that, for normal speeds, the results of these tests are comparable with those obtained in the various other series of tests, but that extraordinarily high figures were obtained when the firemen carrying out the tests were deliberately hurrying and pushing to achieve maximum rate of discharge (Tests 21, 27 and 32). Obviously these high figures, while interesting for comparison purposes, cannot be applied to actual fire conditions, as an undisciplined crowd, discharging in conditions which might be less favourable than those of the tests, could not be expected to attain the high discharge rates reached by a body of disciplined men. It is also worthy of note that in one of these high speed tests (No. 13) a mishap occurred due to some of the men falling on the stairs. This mishap slowed down the movement and gave a figure for discharge rate comparable with that for normal speed. The occurrence of such an incident provides a further reason for discounting the discharge figures for high speed tests.

217. At the other end of the scale the U.S. Bureau of Standards publication notes the leisurely exit conditions in the normal emptying of theatres; conditions which are reflected in the very low discharge figures of Test 47. A higher discharge rate than this would be expected in the event of fire. That this is not necessarily the case, however, is indicated by a recent fire in a provincial theatre. The theatre was in use for the entertainment of a Services audience, and the time taken for the audience to leave the building was stated to be 6 or 7 minutes, an interval very much longer than would have been required if the exits provided had been used to capacity. The discharge time was only noted incidentally in the course of fire fighting operations, and cannot therefore be regarded as an accurate observation; nevertheless it gives a sufficiently clear indication that a crowd which is not in immediate danger, as in this case, especially a disciplined crowd, may not show any great urgency in the use of exits, with the result that the discharge rate may be comparatively low.

PRESSURE AND FLOW FROM A WAITING CROWD

218. The U.S. Bureau of Standards publication notes that conditions of maximum flow occur only when a number of people are waiting to enter an exit. This observation is reflected in the test results. In the controlled tests (Nos. 44 and 53), for example, a crowd of people was assembled at the staircase and asked to ascend or descend as they naturally would, without attempting to run. In these conditions higher figures were obtained than in cases where the people left their offices and moved down the stairs in the normal way. A similar, but not so well-marked result, was obtained in another case (Test 45). In this test, made under fire-drill conditions, the population was concentrated at the stair in question by closing another stair ordinarily used, and a further concentration occurred on the stair itself because the flight under observation was served by two 5 ft. stairways connected to a common landing. It will be noted that the discharge rate for this test was higher than for the others in the series with the exception of the controlled tests mentioned above. The effect of a waiting crowd on discharge through doors

may also be observed. The railway station tests (Tests 55, 62 and 63) were made when gateways were opened to let through crowds which had been waiting in the concourse, and it will be noted that the resulting discharge rates are higher than for office buildings. A similar effect is noticeable, comparing Tests 59 and 60, the discharge rate being higher with one door leaf shut so that the people were concentrated at a narrow opening.

RELATIVE EFFECTIVENESS OF WIDE AND NARROW EXITS

219. In examining the test results it is difficult to separate the effect of this factor from that of the other factors already mentioned. In the results of the French tests (16–33) there appears to be no significant difference in discharge rate per unit width between exits 1 metre wide and 3 metres wide, a width range which covers normal exit sizes. The U.S. Bureau of Standards publication, on the other hand, states that stairways 3 to 4 ft. wide appear to give higher discharge rates than those 7 or 8 ft. wide, especially where the wider stairs have no intermediate handrails. It was noted in the case of an 8 ft. 1 in. wide stair (Test 42) that even with a number of people waiting to use the stairway the crowd, as soon as it entered the stair, became spread out, reducing the discharge rate.

220. The somewhat slender evidence available seems, then, to indicate that under controlled test conditions discharge is proportional to exit width, but that in normal, random flow conditions, narrow exits give higher discharge rates per unit width than wide ones, especially in the case of wide stairs which have no intermediate handrails. In this connection it should be noted that in certain types of buildings the L.C.C. and New York Codes give population figures which are proportionately greater for wide exits than for narrow. The L.C.C. requirements, for example, in the case of single-staircase buildings used for trade purposes or offices, allow a total distributed population of 150 with a 3 ft. 6 in. stair (two units) and 300 with a 5 ft. 0 in. stair (approximately three units), *i.e.* for a 50 per cent. increase in stair width the permissible population is doubled. It is, of course, necessary to bear in mind that an increase in stair width gives a proportionately greater increase in the total area of stairs and landings, and, therefore, in the capacity of an enclosed and protected stair in its function as a place of comparative safety to hold the occupants of a building while evacuation is proceeding.

OTHER CHARACTERISTICS OF MOVEMENT IN EXITS

Difference between Stairs, Doorways and Ramps

221. In the French tests (Nos. 16 to 33) the discharge rates for the horizontal opening are very much higher than those for the staircase. No such well-marked difference can be seen in the tests made under random flow conditions. The U.S. Bureau of Standards publication states that under similar traffic conditions the discharge rate through doorways is higher than up or down stairways. Examination of the test results seems to confirm this finding as a general tendency, but shows that the difference is not very considerable and is obscured by the difference in test results for any one type of exit under different conditions. The L.P.T.B. observations showed little apparent difference between stairs and subways. It seems that, under practical conditions, there is no great difference between the discharge rate for stairs, doorways, passages and ramps.

Difference between Movement Up and Down Staircases

222. The French tests (Nos. 22 to 33) give an interesting comparison in this respect. It will be noted that at normal walking pace the movement downstairs is slightly faster than that upstairs, but that at maximum discharge, hurried and pushing, movement upstairs is quite distinctly the faster. These results are

confirmed by everyday experience, as it is normally easier to go down a staircase, but in running there is less liability to stumble when going up. The other test results do not indicate any very clear difference between movement up or down stairs and it is considered that for escape purposes the difference can be neglected.

Effect of Spacing of People on Staircases

223. The U.S. Bureau of Standards publication notes that, for any given condition of use, the discharge rate for a staircase is nearly the same whether there is rapid movement requiring a considerable space between the people on the stair, or slower movement with the people more crowded together.

Effect of Slight Variations in Width

224. The tests do not give any reliable evidence on the effect of small differences of width, say 6 in. increments. This question is important in relation to the measurement of exit widths in units, and the discharge capacity of exits which are not an exact number of units of width, and will be discussed later (paragraph 228 *et seq.*). It is probable that satisfactory experimental evidence could only be obtained under controlled test conditions in which the effect of other variables could be eliminated.

EXISTING CODE FIGURES FOR DISCHARGE RATE

225. The B.I.N.C. Code gives a discharge rate of forty persons per unit width per minute. In that Code only whole units of width are considered to be effective, but a concession is made in the boundary conditions to minimize the effect of the abrupt change in width from one exact number of units to the next higher exact number of units. Where the calculated number of units of width contains a fraction less than $\frac{3}{10}$, the next lower whole number of units may be taken. This is equivalent to allowing a slightly increased discharge per unit at the boundary value; for example, the limiting discharge rate for exits two units wide would correspond to a calculated width of 2·3 units giving $2{\cdot}3 \times 40 = 92$ persons per minute. The limiting discharge rate would therefore be forty-six persons per unit width per minute.

226. The U.S. Bureau of Standards publication already mentioned recommends discharge rates of forty-five persons per unit width per minute for stairways and sixty persons per unit per minute for doorways. In the code given in that document the problem of fractional unit width is dealt with by allowing 12 in. in excess of an exact number of units to rank as half a unit. On this basis there may again be some little difference between the discharge rate reckoned according to the code and the discharge rate calculated on the assumption that fractions of a unit have a pro-rata value. It should also be noted that, in this code, no specific relationship is given between the discharge rates quoted above and the requirements for exit width.

Recommendation on Discharge Rate through Exits

227. In fixing a discharge rate for calculating exit width requirements, the rate required is the maximum rate at which people can be expected to get out of a building safely in circumstances where they feel that they are in immediate danger. It is reasonable to expect that they would move faster than a crowd moving in a leisurely way out of a theatre. On the other hand, it seems desirable, in comparison with the higher test figures, to make some allowance for the contingencies of fire conditions.

Reviewing the various test results it seems that the practical range of values for the discharge rate during escape would be about thirty to forty-five persons per unit width per minute. The lower values might apply in such cases as office buildings, where the occupants would reach the exits in a steady stream, and the higher values to places where a crowd would be likely to gather at the exits. Owing to the considerable effect of the other factors already mentioned, however, it is not possible to distinguish between different occupancies as regards discharge conditions. It is suggested that a figure of forty persons per unit width per minute should be adopted for the purpose of calculation.

USE OF UNIT WIDTHS

GRADATION OF WIDTH

228. Existing requirements for width of exits are stated in some codes in terms of whole units of width, and in other codes in feet and inches. It is necessary to look at this question in relation both to theory and practical considerations. The use of unit widths is a development of the idea that movement in exits can be expressed as a theoretical equivalent in terms of moving files of people. This is necessarily a simplification of the complex conditions which must arise in practice, but it provides a useful basis for an approach to the problem of exit width requirements. If the width of an exit is an exact number of units the discharge rate per unit derived from tests can be applied with some confidence. If, however, the exit is 6 in. or even 12 in. wider than an exact number of units, it is not possible, on the basis of available test results, to say with assurance that the increased width will give a corresponding increase in discharge capacity. There is reason, therefore, for considering only whole units of width to be effective.

229. On the other hand, it is desirable, from a practical point of view, that increments of width should not be unnecessarily large. If, for example, a 2-unit, *i.e.* 3 ft. 6 in., stair had a discharge capacity slightly less than was required, it would in many cases be inconvenient and uneconomic to provide a 3-unit, *i.e.* 5 ft. 3 in., stair. Also, the validity of the idea that only whole units of width are effective may be questioned on the basis of the fact, confirmed by everyday observation, that people do not move down staircases or through doorways in regular files. From the point of view of common experience it is natural to adopt the summary conclusion that even a small increase in the width of an exit will allow a greater number of people to pass through it in a given time. A 4 ft. 6 in. stair, say, would only take two files of people, the same as a 3 ft. 6 in. stair, and would therefore, in theory, have the same discharge value, yet everyday experience suggests that a crowd of people would actually, in emergency, feel safer and get out more quickly with the wider stair.

230. The problem arises that if the number of people which can pass through an exit in a given time increases steadily with gradually increasing exit width, the idea of unit widths is of no particular value except as a means of calculation. On the other hand, if there is a comparatively rapid increase in the discharge capacity of exits at or near the widths corresponding to exact numbers of units, the unit width idea is obviously important. The limited number of test results available gives a slight, but not sufficiently reliable indication that a small increase in exit width above an exact number of units is comparatively ineffective. Unfortunately, the considerable variation in the test results for any given width makes it impossible to state any reliable conclusion about differences due to small increments in width. Before this question can be definitely settled it will be necessary to get experimental conditions where reasonably consistent results can be obtained for each particular width.

231. In view of the conflicting claims of theory and practical desiderata and

the absence of clear evidence from test results, it is necessary to look closely at the requirements of existing codes.

232. The B.I.N.C. Report adopts the position, in strict conformity with theory, that only whole units of exit width are effective, *i.e.* that increase in width to give increased discharge capacity should be in increments of a unit (1 ft. 9 in.). As already noted, however (paragraph 225), the abrupt transition in width from one exact number of units to the next higher exact number of units is minimized by a provision which is equivalent to allowing a slightly increased discharge per unit at the boundary value. The L.C.C. and some American codes make an allowance for increments of width less than a unit. In the L.C.C. Code stair widths are increased in gradations of 6 in. to provide for an increasing total population. This may be regarded as a successful practical application of the principle of allowing for fractions of a unit width, the choice of 6 in. increments avoiding the complications of smaller fractions and facilitating its use in practice. The New York Code allows 3 in. increments in some cases. Some American codes, including the Canadian and N.F.P.A., adopt the compromise of allowing 12 in. in excess of an exact number of units to rank as half a unit.

233. The 2-unit stair is of general utility, as it is a convenient minimum width without excess which may be of doubtful value for discharge purposes, and a handrail can readily be provided for all the people who use it. There remains, however, the fact that in individual cases it may frequently be necessary to provide for a small excess of population above the figure which would be catered for by the nearest whole number of units, when it would be extravagant to add another whole unit of width. Further, in large buildings, where frequent passing of people on stairs may be expected, a width somewhat in excess of 2 units will be desirable. In view of the variation in existing test results and code requirements, it is considered reasonable, pending the production of more conclusive experimental data, to give priority to these practical considerations and allow small increments of width to be considered of proportionate value.

234. It might be considered that this provision invalidates the idea of using unit widths and that it would be more convenient to calculate exit widths in feet and inches direct. It is recommended, however, that the use of unit widths be retained as a basis for calculation which will probably be useful in future experimental work on the subject.

VALUE OF UNIT WIDTH

235. The value given for the unit of width varies slightly in different codes. In the B.I.N.C. Report the basic value for the unit of width is 21 in. For exits more than 2 units wide, however, units after the second may be 18 in. wide, subject to the restriction that, in new buildings, 4- or 6-unit stairways should be divided by handrails into separate stairs each having a minimum width of 39 in. In the case of existing buildings a reduction of 4 in. is allowed for exits of more than one unit. The above requirements can be tabulated thus:

TABLE 7

Number of units	2	3	4	5	6
Minimum width required for a new building	42 in.	60 in.	78 in.	96 in.	114 in.

236. In American codes the most commonly accepted value for the unit of width is 22 in. This width is specified, for instance, in the Canadian, N.F.P.A. and New York Codes. Certain relaxations in the case of the N.F.P.A. Code should, however, be noted. In the case of doors, 20 in. of net opening is accepted per unit, and in existing buildings a stairway 40 in. wide is accepted as 2 units. In existing outside fire-escape stairs 18 in. width between handrails is accepted as one unit. The Californian Code makes 18 in. the unit of exit width in all cases.

237. It may be noted that the effect of the variations in unit width on the discharge value of exits is not critical. For instance, the difference in discharge value between a 3-unit exit 5 ft. 3 in. wide and one 5 ft. 0 in. wide would be a fractional difference of only $\frac{1}{21}$. It is reasonable to accept the idea that on a wide stair there is less likelihood than on a narrow one of the full width being occupied by persons of broad build, and that for wide stairs the unit of width can be reduced on that account. On the other hand, it has already been noted (paragraph 220) that there is some evidence that the discharge from wide stairs is proportionately less than from narrow stairs, so that any excess width which may be provided by maintaining a constant value for the unit would help to compensate for this. In this Report, therefore, we have used a figure of 21 in. as a basis for calculation.

MINIMUM AND MAXIMUM WIDTHS OF STAIRCASES

238. Although it has been recommended that small variations in exit width should be assumed to have a proportionate value for discharge purposes, it would seem desirable to place some limit upon the application of this principle to narrow staircases and it is recommended therefore that staircases and exits should generally be not less than 2 units (3 ft. 6 in.) wide. Where exits or staircases serve a limited number of persons, however, this width could be reduced to a minimum of, say, 2 ft. 6 in. for not more than 75 persons, although we consider that apart from exceptional circumstances, a minimum width of 3 ft. for staircases would be more desirable. In flats and other single-staircase buildings with a sleeping risk we recommend that the staircase should under no circumstances be less than 3 ft. wide and in similar buildings over four storeys in height it should be not less than 3 ft. 6 in. wide.

239. Persons passing down the centre of a wide staircase may stumble and fall through having no handrail to grip. In a two-unit staircase a handrail is available for each stream of traffic, and in a three-unit staircase, although no handrail is available for the centre stream, any person in this stream who should stumble could cling to someone in one of the two side streams, each of which has a handrail for its use. The risk of persons falling in the centre streams of staircases more than three units wide would, however, be much greater, and it is recommended therefore that no staircase should be more than three units wide unless it is divided by a handrail or handrails into sections of not less than two units or more than three units wide. For the purpose of this recommendation only, a width of 6 ft. 0 in. should be regarded as not more than three units wide.

240. The width of staircases should be measured between the finished surfaces of walls or to the outer edges of steps. Handrails should not project more than $3\frac{1}{2}$ in. each side into the measured width.

CALCULATION OF EXIT WIDTH

241. The determination of exit width, whether it applies to door openings or to stairways, involves consideration of the movement of numbers of people. In looking at this question from first principles it is immediately apparent that two

distinct sets of conditions may arise. Firstly, the people may all be on a single floor, the term "floor" in this connection including such instances as a theatre balcony or the stepping of a grandstand. Secondly, the people may be on a series of floors all of which are served by the same staircases. In this second case we have not only to think of the discharge from the individual floors on to the staircase, but also of the way in which the streams of people from the various floors intermingle on the stairs. In theatres and other occupancies where there are separate stairs from each level, the discharge conditions are essentially similar to those which occur where there is a single floor.

STAIRCASES SERVING A SINGLE FLOOR

242. For a given number of people on a single floor, the discharge conditions are controlled by the time taken for the people to pass through the exits. Narrow exits which only allow the floor to be cleared slowly are liable to cause irritation among a waiting crowd. In emergency this may lead to panic and crushing. Exits must therefore be wide and numerous enough to clear the people before their anxiety can reach this pitch.

243. The determination of a suitable clearance time to be used as a basis for calculation is a matter of experience and judgment. Unfortunately little information is available about the time taken to empty buildings under actual fire conditions. A case which should be mentioned, however, is that of the Empire Palace Theatre fire in Edinburgh in 1911. There was a large audience in this building when fire broke out on the stage, and the available evidence indicates that the time taken to clear the building was about 2½ minutes (see Home Office *Manual of Safety Requirements in Theatres*). Certain measurements which have been made of the time taken to empty theatres under normal conditions, suggest that if the auditorium is cleared in 2½ minutes there will be no serious risk of panic in the event of fire. The B.I.N.C. Code gives figures for clearance time varying from 2 to 3 minutes according to the type of construction. Most codes do not make any explicit statement on the subject of clearance time, but this factor is controlled indirectly by the requirement for exit width. In this connection it should be noted that, in the case of assembly occupancies, there is a fair measure of agreement between the exit width requirements of the various codes which, taken in conjunction with a discharge rate of 40 persons per minute, give an average clearance time of 2½ minutes. It is proposed to adopt this figure as a basis for calculation.

244. The influence of the construction, finishings and contents of buildings on the choice of clearance time needs consideration. As regards construction, it is unlikely that fire, in its early stages, would affect the main structure of a building sufficiently to influence the safety of the occupants during the short time interval required for evacuation. More important is the question of flame spread on combustible surface finishes and the possibility of rapid spread of fire in inflammable contents and decorations. Certain recommendations on the nature of surface finishes have been suggested in Section 1 of this Part of the Report. If these recommendations are observed it is not considered that the safety of the occupants will be seriously affected by the nature of the structure or finishings to such an extent that any variation need be made in clearance time. The question of inflammable contents requires special consideration in such cases as workrooms where highly inflammable substances are handled. In those instances, however, the provision of exits should be considered in relation to other precautions for fire safety, and each case should be considered on its merits.

245. A further factor which affects the question of clearance time for any floor area is introduced if the floor is not at ground level, so that the occupants have to move up or down stairs. If an open staircase communicates directly with the

floor area, the time taken to traverse the stairs would naturally be included in the total time interval allowed for evacuation. In occupancies such as theatres, however, where each level is provided with separate enclosed and protected staircases, the evacuation could reasonably be considered complete when all the occupants had passed into the staircases.

246. The discharge values of exits of different widths from a single floor may now readily be calculated. On the basis of a discharge rate of 40 persons per unit per minute and a clearance time of 2½ minutes, each unit of exit width could deal with 40×2½=100 persons per minute. A 2-unit staircase would thus be capable of discharging 200 persons. Corresponding discharge values for exits ranging from 3 ft. 6 in. to 6 ft. are given in Table 8. Before making use of this Table for obtaining exit widths for assembly buildings reference should be made to Table 5 which gives the minimum number of exits for varying total populations in such buildings. In addition, where any floor is below ground or more than 20 ft. above ground, a modified discharge value should be adopted as described in paragraph 247.

TABLE 8. BUILDINGS WITH A SINGLE FLOOR OR SEPARATE STAIRS FROM EACH FLOOR —DISCHARGE VALUES OF EXITS OR STAIRCASES

WIDTH OF EXIT OR STAIRCASE	3′ 6″	4′ 0″	4′ 6″	5′ 0″	5′ 6″	6′ 0″
Discharge value for evacuation time of 2½ mins.	200	230	260	290	310	340

247. Although a figure of 40 persons per unit width per minute has been recommended as generally applicable, it is probable that in a high staircase serving one floor only, such as one from a theatre balcony, the rate of movement may tend to diminish after several flights have been traversed. To allow for this factor it is recommended that for every 10 ft. of height in excess of 20 ft. above the ground, and for every 10 ft. below ground, 8 per cent. should be added to the calculated number of persons who will use a staircase, before reading its width from Table 8. For example, if a staircase serving a single floor is 60 ft. high, and the calculated number of persons who will require to use it is 200, an addition of 4×8 per cent. of 200=64 should be added to the figure of 200 before reading the requisite width from the Table. This gives 200+64=264 and the width, from Table 8, would be 4 ft. 6 in.

STAIRCASES SERVING A NUMBER OF FLOORS

248. When we come to deal with this question we find that existing codes approach the problem in quite different ways, and that there is a wide divergence in their requirements. The problem does not readily admit of a simple, rational solution, such as has been obtained for the case of a single floor. If fire breaks out on one of a series of floors, it is practically impossible to predict how quickly the occupants will respond to warning of fire, or the order in which the various floors will be evacuated. In practice, these will depend on a number of factors; the type of people concerned, their state of alertness and discipline, their confidence or lack of confidence in the fire protection of the building, the method of giving warning of fire, and so on. Obviously some basic assumptions have to be be made if any rational solution to the problem is attempted. Some codes give requirements which are simply arbitrary rules based on experience. The weakness of these is, of course, that while experience may indicate that the requirements are sufficient, it does not give a clear indication whether they may not, in fact,

be excessive. Purely empirical rules are also liable to give results which are inconsistent when applied to a wide range of cases.

249. In those codes which do attempt to deal with the problem on rational lines, one of the following methods is used:

1. Stair width based on the population of one floor.
2. Stair width based on the population of one floor but using a modified discharge rate value.
3. Stair width based on total population.
4. Stair width based on capacity of stairs.

In the following paragraphs these methods are discussed in relation to actual discharge conditions.

EXISTING METHODS OF DETERMINING STAIRCASE WIDTH

STAIR WIDTH BASED ON THE POPULATION OF ONE FLOOR

250. This method gives the minimum figure for stair width owing to the fact that provision is made for evacuating only one floor at a time. The basis of the method is that if sufficient stair width is provided to evacuate in an appropriate clearance time the people on the floor immediately affected by the fire, those on other floors can find their way out thereafter without serious risk. There is some force in this argument when applied to buildings of fully protected construction in which the floors have sufficient fire resistance to prevent penetration of fire. Even in the most favourable conditions, however, we do not think it safe, in calculating stair width, to neglect the flow of people from the floors above and below the one on which fire breaks out. When warning of fire is spread with reasonable promptness it is likely that there will be people from all the floors trying to get on to the staircases at the same time. The evacuation will no doubt be speediest from the floor immediately affected, but the conditions of movement on the stairs will be influenced by people coming from other floors.

STAIR WIDTH BASED ON A MODIFIED DISCHARGE RATE VALUE

251. Whilst in the above method the effect of discharge from floors other than the one immediately affected is neglected, some codes make allowance for it by adopting a discharge rate which is less than the rate for a single floor. For instance, the N.F.P.A. Code gives a figure of 60 persons per unit in the case of buildings with a number of floors, which is lower than the figure of 100 persons per unit given for a ground floor. The effect of this is that stair width is greater than that required for one floor only. This probably represents a more reasonable solution to the problem, but it can be criticized on the ground that it does not differentiate between buildings with different numbers of floors. A building with two floors would have the same stair width as one with ten floors and a much greater total population. The results may well be satisfactory in the case of buildings of average height, but become inconsistent when applied over a wide range.

STAIR WIDTH BASED ON TOTAL POPULATION

252. Looking at the problem of escape from the point of view that it should be possible to evacuate all the people in a building in a reasonable time, it seems logical to base stair width on total population rather than on floor population. The difficulty arises, however, that if an attempt is made to provide staircases wide enough for a building to be completely cleared in 2½ minutes, their width will be excessive in the case of buildings of moderate height, whilst it will be a physical impossibility to clear a high building in such a time owing to the distance

which must be traversed from the top floor to the ground. An increase in overall clearance time is inevitable as the height of the building is increased. The B.I.N.C. Code requirement for stair width in department stores is of interest in this connection. The width asked for is half the sum of the number of units required for all floors. In other words stair width is based on total population, but the clearance time will be twice as great as for a single floor, assuming that the discharge rate remains constant. This method gives results which may be reasonable for buildings of low or medium height but will be extravagant for high buildings. If, however, the need for allowing an increased clearance time for buildings more than one storey high is accepted, it seems illogical not to vary the allowance generally according to the height of the building. Provided the staircase is properly enclosed and protected it may be looked upon as a place of safety in the event of fire, and the significant clearance time is the time taken for all persons to leave the various floors and reach the security of the staircases. If this time is maintained at 2½ minutes it would be reasonable for the overall clearance time to increase as the building increases in height.

STAIR WIDTH BASED ON CAPACITY OF STAIRS

253. This method deals with the problem from quite a different angle, space and not time being the basic factor. The underlying idea is that a sufficient area of staircase (treads and landings) should be provided to accommodate all the people on the stairs, a protected stair being looked on as a place of refuge as well as a route to the outside of the building. With this method the stair width is independent of the number of floors, yet the increase in total population with increasing number of floors is automatically allowed for by the increase in staircase capacity. On a capacity basis, then, the total population is provided for without, in very high buildings, leading to the extravagant results which may be given by a method which makes stair width increase in direct proportion to the number of floors.

254. The main difficulty raised by this method is that, if sufficient space is allowed per person to permit reasonably free movement, the stair width is somewhat excessive compared with what is indicated by current practice. The space per person will fall within a range of values varying between a minimum of about 1½ sq. ft. with the people tightly packed, and a figure of 4 sq. ft. or even more which is required for maximum discharge rate. The New York Code asks for 2¾ sq. ft. per person on landings and allows 1 person per unit width on alternate steps (equivalent to about 3 sq. ft. per person). The N.B.F.U. Code requires 3½ sq. ft. per person. If only the minimum space per person is provided, a reasonable figure for stair width is obtained, but this is based on a condition in which free movement is no longer possible, a condition which is opposed to the fundamental conception that escape is essentially a process involving movement. The capacity method can also be criticized from the point of view that it does not differentiate between low buildings and those with a large number of floors. The principle adopted would seem to provide a reasonable basis for the calculation of staircase width in high buildings, but would produce extravagant results in low buildings.

SUGGESTED METHOD OF DETERMINING STAIRCASE WIDTH

255. It appears from the foregoing discussion that none of the existing methods of assessing staircase width cater generally for the conditions which arise on a staircase serving a number of floors. There appear to be two main factors which a rational method should satisfy; first, that it should be based on a reasonably accurate conception of the flow which occurs on a staircase when all floors are

discharging at the same time, and second, that it should take account of the conditions which may arise when a fire starts. The method described in the following paragraphs and amplified in Appendix II attempts to satisfy these conditions. Whilst it appears to avoid the inconsistencies apparent in other methods it is, however, based on certain assumptions and assumed values which are stated in the Appendix. In order to confirm the fundamental ideas involved it would seem desirable that a series of experiments should be made. Such experiments would necessarily have to be on a rather extensive scale and, even so, it would be difficult to simulate all the considerations which enter into the calculations. It may be noted, however, that the adoption of some of these considerations amounts virtually to the introduction of a factor of safety.

256. It is necessary, first, to consider the movement of people from a number of storeys on to a common staircase, and to determine how many people can be catered for by a given width of staircase from a number of storeys. The flow of people from each storey on to the stairs can be considered to occur in two stages:

1. The filling up of each storey height of stairs by persons from the storey at the top of each section. During this period full and uninterrupted flow from each storey on to the stairs can occur.
2. The subsequent flow. After the staircase is filled flow conditions change, and the flow from each storey on to the stairs is determined by the rate at which people pass out of the exit door at street level, *e.g.* if 80 people per minute pass into the street, 80 people per minute can enter the stairs, and if there are four storeys each could supply 20 persons per minute, assuming that each storey contributes an equal number of persons.

If the time for clearance *of each storey* is limited the population of each floor will also be limited, and the sum of (1) and (2), determined on the basis of the limited clearance time, will be the number of people per floor which can safely be catered for by the staircase. This number per floor multiplied by the number of storeys gives the total population of the building. It will be noted that clearance time relates to the clearance of the separate storeys, and not of the building as a whole. For further details of the calculation, and of the assumed values on which it is based, reference should be made to Appendix II. Results for four widths of stair are given in Table 9 for buildings having from 2 to 10 storeys above the ground storey, for which storey provision should be made on the basis discussed in paragraphs 267-268.

TABLE 9. DISCHARGE VALUE OF ONE STAIRCASE SERVING SEVERAL STOREYS

NO. OF STOREYS ABOVE GROUND STOREY	TOTAL NUMBER OF PEOPLE IN BUILDING ABOVE GROUND STOREY			
2	236	270	310	340
3	270	310	360	400
4	304	360	410	460
5	338	400	460	520
6	372	440	510	580
7	406	480	560	640
8	440	520	610	690
9	474	570	660	750
10	508	610	710	810
Width of Stairs	3′ 6″	4′ 0″	4′ 6″	5′ 0″

257. The discharge values in the above Table were obtained without regard to fire conditions and *they therefore cannot be used directly to determine exit width requirements*. For example, it cannot be assumed that two staircases each 3 ft. 6 in. wide could safely cater for $2 \times 270 = 540$ persons in a building with three storeys above ground, on the basis that two staircases can cater for twice the number of a single staircase. There are several factors to be considered and we deal with them below.

TWO-STAIRCASE BUILDINGS

258. The main problem arises from the risk that one staircase may become wholly or partly unusable, *e.g.* if a fire occurs on a lower floor and a door is left open. The population may then be forced to use the remaining staircase. The risk of both staircases being rendered unusable is considered sufficiently remote to be neglected. There are several factors which must be considered in order to decide what reduced discharge value can be assigned to one of the two staircases or whether, in fact, one should be wholly neglected. The main factors are:

1. Type of construction.
2. Nature of occupancy—contents and use.
3. Whether the building is sprinklered or not.

Type of Construction

259. In a building of Type 1, 2 or 3 (fully protected) construction conforming generally to the recommendations we have made in Part I and earlier in this Part of our Report, the risk of the whole of one staircase being rendered unusable is less than that arising in lower grades of construction (Types 4 and 5). The construction is by no means a decisive factor, since we are concerned only with the earliest stages of the fire before it has reached major proportions. There is some justification for greater allowance being made in favour of the fully protected construction, but the primary consideration is the combustibility of the construction rather than its grade of fire resistance.

Nature of Occupancy

260. It will be evident that greater risk arises in those occupancies in which inflammable materials are stored or are in use and which we described in Part I as having abnormal risk. The more rapid development of fire in such occupancies tends to greater risk of a staircase being made unusuable earlier should there be any unforeseen defect in the enclosure of the stairs. In residential occupancies the "sleeping risk" introduces factors of a different kind, but leading to a similar ultimate result.

Effect of Sprinklers

261. The installation of a sprinkler system in a building reduces the fire hazard and there is, therefore, less risk of a staircase being rendered unusable.

262. It is apparent, therefore, that the extent to which the second staircase can be considered available will vary in different instances. In no case do we consider it advisable to give it full allowance, even though we have asked for enclosure to all staircases, but propose that an allowance ranging from one-quarter to three-quarters be made as shown in Table 10, according to the construction of the building and the nature of the occupancy.

TABLE 10. PERCENTAGE ALLOWANCE FOR SECOND STAIRCASE

OCCUPANCY OR CONSTRUCTION	PERCENTAGE ALLOWANCE FOR SECOND STAIRCASE
1. All occupancies in buildings of Types 4 and 5 construction 2. Shops and department stores; factories with abnormal risk	25
Residential occupancies Occupancies in (2) above if sprinklered	50
Offices Factories with normal risk	75

263. In Table 11 we give the width of staircases required in two-staircase buildings for various populations, based on the above allowances for the second staircase. The populations would be determined from the floor area on the basis of the recommendations we have made in paragraph 82. It should be noted that the figures in Table 11 are based on the assumption that the total population is fairly evenly distributed over all the floors of a building. When any one or more floors has a population appreciably different from the average for the building, a study must be made of conditions in each case, on the basis of the principles described in Appendix II.

BUILDINGS WITH MORE THAN TWO STAIRCASES

264. The simplest method of determining the widths of staircases in buildings with three or more staircases follows directly from the foregoing discussion on two-staircase buildings. For example, in a three-staircase building it is only necessary to consider again the risk of one staircase being put out of action by fire. The full discharge value can therefore be assigned to two staircases and a proportion of the discharge value to the third staircase varied again in accordance with Table 10. The widths, determined on that basis, of each of the three staircases required for various populations in three staircase buildings are shown in Table 12.

265. Such a method has the merit of simplicity. It provides for stairs of minimum and equal width but is not completely satisfactory, particularly in those instances where the population or staircases are irregularly disposed. To deal with these satisfactorily, careful analysis of the building is necessary to ensure that each staircase will be adequate to meet the demand which may be expected of it in an emergency. This analysis is carried out by assuming, for the purpose of calculation, that one of the stairs is rendered unusable by fire, and an allocation is made to each of the remaining stairs of those parts of the calculated population of a storey who would then normally be expected to use these stairs. Some analysis of this kind is essential in large multi-stair buildings if proper provision for staircase accommodation is to be made, but further study is needed before comprehensive recommendations are possible. However, as an illustration, a simple example is considered in Appendix III. In buildings with more than three staircases a study of conditions on such lines is even more necessary and no tables are given. Where the population is not evenly distributed over all floors, the remarks in paragraph 263, under two-staircase buildings, are equally applicable.

TABLE 11. TWO-STAIRCASE BUILDINGS. MINIMUM WIDTH OF EACH STAIRCASE

(Population distributed over all floors)

NO. OF STOREYS ABOVE GROUND STOREY	CALCULATED NUMBER OF PEOPLE IN BUILDING ABOVE GROUND STOREY											
	SHOPS, DEPT. STORES AND ABNORMAL RISK FACTORIES—NOT SPRINKLERED; ANY BUILDING OF TYPE 4 OR 5 CONSTRUCTION *				SHOPS, DEPT. STORES AND ABNORMAL RISK FACTORIES—IF SPRINKLERED; RESIDENTIAL BUILDINGS				NORMAL RISK FACTORIES; OFFICES			
2	300	340	380	430	350	400	450	510	410	470	540	600
3	340	390	440	500	400	460	530	600	470	550	630	710
4	390	450	510	580	450	520	600	680	530	620	710	810
5	430	500	570	650	500	590	680	770	590	700	800	910
6	470	550	630	720	560	660	760	860	650	770	890	1010
7	510	600	690	790	610	720	830	950	710	850	980	1110
8	550	650	750	860	660	780	910	1040	770	920	1070	1210
9	600	710	820	940	710	840	980	1120	830	1000	1160	1320
10	640	760	880	1010	760	910	1060	1210	890	1070	1240	1420
Minimum width of each Staircase	3′ 6″	4′ 0″	4′ 6″	5′ 0″	3′ 6″	4′ 0″	4′ 6″	5′ 0″	3′ 6″	4′ 0″	4′ 6″	5′ 0″

* Buildings of Type 4 or 5 construction should be limited in height—see Part I.

TABLE 12. THREE-STAIRCASE BUILDINGS—MINIMUM WIDTH OF EACH STAIRCASE (*see also paragraph* 265)
(Population distributed over all floors)

NO. OF STOREYS ABOVE GROUND STOREY	CALCULATED NUMBER OF PEOPLE IN BUILDINGS ABOVE GROUND FLOOR											
	SHOPS, DEPT. STORES AND ABNORMAL RISK FACTORIES—NOT SPRINKLERED; ANY BUILDING OF TYPE 4 or 5 CONSTRUCTION *				SHOPS, DEPT. STORES AND ABNORMAL RISK FACTORIES—IF SPRINKLERED; RESIDENTIAL BUILDINGS				NORMAL RISK FACTORIES; OFFICES			
2	540	610	690	770	590	670	760	850	650	740	840	940
3	610	700	800	900	680	780	890	1000	740	860	980	1100
3	690	800	910	1030	760	880	1010	1140	830	970	1110	1260
5	760	890	1020	1160	850	990	1140	1290	930	1090	1250	1420
6	840	990	1140	1300	930	1100	1270	1440	1020	1200	1390	1580
7	920	1090	1260	1430	1020	1210	1400	1590	1120	1320	1530	1740
8	1000	1180	1370	1560	1100	1310	1520	1730	1210	1440	1670	1910
9	1070	1270	1480	1690	1190	1420	1650	1880	1310	1560	1810	2070
10	1150	1370	1590	1820	1270	1520	1770	2020	1400	1670	1950	2230
Minimum width of each Staircase	3′ 6″	4′ 0″	4′ 6″	5′ 0″	3′ 6″	4′ 0″	4′ 6″	5′ 0″	3′ 6″	4′ 0″	4′ 6″	5′ 0″

* Buildings of Type 4 or 5 construction should be limited in height—see Part I.

SINGLE-STAIRCASE BUILDINGS

266. Single-staircase buildings are subject to limitations discussed in paragraphs 190-211 as regards height, floor area and total population. Whilst we have in general assumed that the flow through a unit width is 40 persons per minute, and thus for a time of 2½ minutes arrived at a figure of 200 persons for a 2-unit (3 ft. 6 in.) staircase, we consider that some reduction should be made on the full allowance when only one stair is provided. Instead therefore of suggesting that a 3 ft. 6 in. stair should be provided for a single-staircase building with 200 people we have reduced this latter figure by 25 per cent., *i.e.* to 150, and adjusted other figures accordingly (Table 13).

TABLE 13. SINGLE-STAIRCASE BUILDINGS—STAIRCASE WIDTH IN RELATION TO POPULATION

STAIRCASE WIDTH	CALCULATED NUMBER OF PEOPLE IN BUILDING						
	2′ 6″	3′ 0″	3′ 6″	4′ 0″	4′ 6″	5′ 0″	5′ 6″
Where population is mainly concentrated on one or two floors	50	100	150	175	200	225	250
Where population is distributed over more than two floors	75	125	175	225	250	—	—

WIDTH OF GROUND FLOOR EXITS

267. The ground floor population has been excluded from the above Tables for the obvious reason that the occupants of the ground floor do not use the staircases in making their escape. The occupants of both ground and upper floors will, however, frequently make use of the same ground floor exits to the street, and it is important, therefore, that these exits should be of an adequate width for the total population of the building.

268. The calculations described in Appendix II, from which the figures in the above Tables were obtained, are based on the assumption that flow from the upper storeys would not be restricted in any way by persons emerging from the ground floor. If this assumption is to be realized in practice it will be necessary for the ground floor exits, if used by persons leaving the ground floor as well as by those passing down a staircase from upper floors, to be wider than the staircases. Only if the ground floor exit to street is equal in width to the sum of the staircase width plus the width of all other exits leading into the ground floor vestibule will this condition be satisfied. In some cases it may be undesirable to increase the ground floor exit to this extent. The difficulty may be overcome by amending the first column of Tables 11 and 12 to read "Total number of storeys (including ground storey)" and substituting the total population of the building for the population above the ground storey. A similar amendment could be made to Table 13. If this is done, the staircase width will be somewhat increased, and the width of the ground floor exit to street may be the same as the staircase width, since full allowance will have been made in the calculation for obstruction by persons leaving the ground floor.

CONSTRUCTION OF MEANS OF ESCAPE

269. This is one of the most important factors affecting safety of life in fire. Escape facilities, satisfactory in other respects, have in many cases proved disastrously inadequate because of constructional defects. A common instance of faulty

construction is failure to provide for the fire and smoke separation of staircases by enclosures of suitable fire resistance. There have also to be considered such questions as the use of external fire escape stairs and roof exits, and surface finishes in staircases and corridors. Numerous points of detail are also covered by the requirements of existing codes—points such as the length of stair flights, the dimensions of treads and risers, and the direction of opening and method of fastening of doors on escape routes. Some of these details may appear trivial, but lack of attention to them has often been a contributory factor in a fire disaster. For the present purpose, however, it seems appropriate to deal with the subject only in broad outline, leaving matters of detail to be covered in a Code of Practice.

STAIRCASE ENCLOSURE AND CONSTRUCTION

270. The protection of vertical shafts has already been mentioned in Part I of the Report. The need for this protection was there emphasized from the point of view of spread of fire through the building, and consequent damage to the structure and contents. This form of protection is equally important as a life safety precaution. Experience of the spread of smoke, hot gases and fire via open staircases, resulting sometimes in heavy loss of life, underlines the necessity for the enclosure of vertical openings. It is recommended, therefore, that all internal staircases should be enclosed.

271. If the above recommendation is interpreted in a narrow sense it will preclude the design of a staircase as an architectural feature of any building. Obviously maximum safety will be afforded where the enclosing walls of a staircase abut on the steps and landings, and openings in the enclosure are limited to one at each floor level. It may be desired in some buildings, however, to design a main staircase with open balustrades, passing through a series of halls or large landings out of which a number of rooms may open at one or more floor levels. In such an instance the staircase would appear to be "open" and not "enclosed," but it may be considered to be enclosed if the halls or landings through which it passes are themselves enclosed by fire resisting walls or partitions and all openings in such walls or partitions (apart from window openings) are protected by self-closing fire check doors. It must be recognized, however, that a staircase of this type cannot be regarded as being so well protected as one having a normal enclosure, owing to the increased fire hazard arising from the large number of openings in the enclosing walls. It is recommended, therefore, that such staircases should be limited to not more than half the total number of staircases in a building. All remaining staircases should be properly enclosed in the normal manner.

272. As regards the construction of stairs, the use of combustible material would be limited by the provisions of Part I of the Report to buildings of Types 4, 5 and 7 construction. In these buildings, therefore, staircases may be constructed of combustible materials, but we would exclude from this general recommendation single-staircase buildings and schools, institutions and assembly buildings, in which stairs should be constructed wholly of incombustible material.

273. Some degree of fire resistance is obviously desirable in stair construction but no tests on stairs in accordance with B.S. 476 have been made, and fire resistance must, to a large extent, be estimated on the basis of the performance of types of floor construction as nearly similar as possible. It is recommended that stair construction should provide an estimated minimum fire resistance of half an hour. In conjunction with a fire resisting enclosure, stairs having this grade of fire resistance should ensure safety against collapse for a sufficient period to cover the requirements of those occupancies in which the evacuation time is liable to be greatest, *i.e.* residential and institutional buildings.

274. Staircases should, as far as possible, adjoin an outer wall and should be properly lighted and ventilated by windows. They should be so arranged that persons entering them from any floor do so in the direction of flow. We have not thought it necessary to modify or repeat the general details of stair construction which are quoted in existing codes; for example, in the publication of the London County Council dealing with means of escape. One point, however, which calls for mention is that, to guard against persons being injured on the commencement of a balustrade which divides a wide staircase into narrower portions (see para. 239), the newel post at this point should be carried up to a height of not less than 7 ft. 0 in.

FORMS OF STAIRCASE ENCLOSURE

275. The ideal type of enclosed staircase is one arranged in the form of a fire tower, *i.e.* a staircase which can only be approached from the various floors by landings or lobbies separated from both the floor areas and the staircase by fire resisting doors and open to the outer air. This type of enclosure gives practically complete immunity from any danger of the staircase becoming impassable due to smoke or hot gases.

276. With the ordinary types of staircase enclosure, complete protection against smoke and hot gases cannot be assured. Even apart from the necessary opening of doors for escape, smoke may get into the staircase due to doors being opened by the draughts which are caused by fire. The danger is greatest where the staircase serves open floor spaces and there is only a single separation between the stair and the areas where fire may break out. Where the floor areas are subdivided, and access to the stair is by corridors or lobbies bounded by fire resisting partitions, the double separation materially reduces the risk of the stairs becoming smoke-filled. With open floor areas, a double separation can be provided by arranging for the staircase to be entered through a lobby with two sets of self-closing doors.

FIRE RESISTANCE OF STAIRCASE ENCLOSURES

277. This subject has already been dealt with in Part I (paragraph 144) from the point of view of preventing fire spread. The figures for fire resistance given there are generally greater than those necessary to cover escape requirements only, and can therefore be accepted for the present purpose. Where escape is the only factor to be considered, a fire resistance of half an hour should provide a reasonable margin of safety. Doors and glazing in the enclosure should, of course, have a similar fire resistance. A higher grade of fire resistance might be considered advantageous in institutional buildings.

278. In adopting a minimum of half an hour fire resistance for stair enclosures, it is desirable to guard against the use of hollow combustible construction. The possibility that fire may start within a partition of this type, thereby reducing the effective fire resistance, and perhaps concealing the outbreak until smoke and hot gases have passed into the staircase, is a serious matter. It is recommended that hollow combustible construction should not be used for staircase enclosures.

EXTERNAL FIRE ESCAPE STAIRS

279. The use of external stairs as fire escapes is common practice, particularly when additional escape facilities have to be provided in existing buildings. They are generally, but not universally, accepted by existing codes as equivalent to internal enclosed and protected stairs. An important code which does not accept outside stairs in new buildings is that of the N.F.P.A.

280. Whilst under favourable conditions the external fire escape stair is a satisfactory means of escape, there is the possibility that if an outside stair has to be used in darkness and in unfavourable weather conditions, perhaps with ice on the stair treads, evacuation may be very much slower and there may well be mishap and panic. There is also a serious objection to these stairs on the ground that in few cases are they used for normal circulation. Access to them is therefore liable to be obstructed by doors not opening readily, or even by the storage of goods in passages leading to the stairs. This latter possibility also occurs where internal stairs are infrequently used for purposes other than escape, a condition which sometimes arises in buildings where the main circulation is by lifts. It is considered that in new buildings outside stairs should only be used where site or planning restrictions make it inconvenient to have all staircases within the building, and then only if partially protected by some permanent covering against the weather.

281. Where external fire escape stairs are used, it is essential to take precautions to prevent the stairs being made impassable by smoke or flame from adjacent window openings or from doors leading to the stairs. All such doors below the top storey should be self-closing and should have a fire resistance of at least half an hour. If smoke or flame from nearby windows would prejudice the use of the stair, the windows should be of a fixed type with fire resisting glazing giving half an hour fire resistance. Any ventilators which are essential for health or other reasons should be designed to minimize the passage of smoke and flame. The following limits of distance are suggested, within which openings adjacent to any platform or stairway should be protected as above:

Horizontal distance	6 ft.
Vertical distance down	30 ft.
Vertical distance up	6 ft.

The distance should be measured in each case from the nearest point of the opening to the edge (for horizontal measurements) or the floor surface (for vertical measurements) of the platform or stair.

SPIRAL STAIRS AND LADDERS

282. Means of escape of these types are of value where space is restricted and provision has to be made only for a limited number of able-bodied persons. The following recommendations are made on their construction and use:

Spiral Stairs. These should not be less than 5 ft. in diameter and not more than 30 ft. high, and should be designed to give adequate headroom. The effective width of a spiral stair may be taken as 1 unit, and the number of people for which escape is provided in this form should not exceed 50.

Raking Step-Ladders. Where these are fixed at an angle to the horizontal not greater than 60°, and do not exceed two storeys or 20 ft. in height, they may be accepted as a means of escape for not more than 30 persons. The treads should be not less than 5 in. wide.

Vertical Ladders. These should only be accepted as a means of escape for not more than 10 able-bodied persons in factories, mechanical installations and similar occupancies. Where they are more than 20 ft. high, intermediate landings should be provided, or alternatively, suitable guards should be fixed, forming an enclosure round the ladders. The strings should be carried up 3 ft. 6 in. above the stepping-off level to give a handgrip.

ROOF AND HORIZONTAL EXITS

ROOF EXITS

283. The use of roof exits has already been mentioned in connection with single-staircase buildings. Such an exit can only be accepted where it is possible to provide access from it to the ground, or to an adjoining building and thence to the ground. It is particularly important to ensure that the roof exit itself is adequately cut off within the building from the staircase below. Without such protection the effect of opening the roof exit may be to draw smoke and hot gases up the staircase, so preventing the use of the exit and promoting rapid fire spread up the stairs. At the level of the top floor, therefore, a fire resisting screen with self-closing fire check doors should be provided, separating the staircase at that level from the staircase below. This is illustrated diagrammatically in Fig. 4. Such protection may be omitted where the staircase serving not more than the top three floors is cut off from the staircase below in a similar way to that illustrated in Fig. 6. Alternatively, in buildings of single occupancy the roof exit may be approached through a room, provided the room is cut off from the staircase by a self-closing fire check door.

284. Where a roof exit is provided it is essential that attention should be paid to the construction and maintenance of any gangways, platforms or stairs leading to the adjacent building, so that safe passage for the occupants will be permanently assured. Surfaces of gangways, etc., should be such as to minimize the risk of slipping, and the escape route should be protected by handrails or parapets not less than 3 ft. 6 in. high. It is also desirable that some form of artificial lighting should be available on the escape route.

HORIZONTAL EXITS

285. The term "horizontal exit" covers a number of arrangements by which alternative egress from a floor area can be provided by giving access to a floor at or near the same level in an adjoining building or an adjoining part of the same building adequately fire-separated from it. The access may be through a division wall, by a balcony, or by means of a bridge between two separate buildings. Where the horizontal exit gives passage through a fire stop wall, the openings in which are protected by fire resisting doors or shutters as required by Part I of our Report, paragraph 142, a notice must be displayed requiring these doors or shutters to be kept open, *i.e.* not to be closed manually, during such time as the doorways may be required for escape purposes. If a fusible link is used the doors must remain openable by hand after the link has fused. Any fire-check doors which may be provided to such openings in addition should be arranged to open clear of the fire resisting doors or shutters when the latter are closed.

286. It will be understood that the legal questions involved when access is provided between adjoining properties cannot be dealt with here. It is assumed for the present purpose that the adjoining buildings are in common ownership, or that the necessary agreement can be reached for access between them. Horizontal exits may be accepted as providing an alternative means of escape, but not as equivalent to an increase in stair width, except in cases where the building to which access is provided has an aggregate width of stairs in excess of that required for its own population. For instance, if two adjoining buildings were of such a size that each would normally require two staircases, an arrangement could be accepted with one stair in each building and an emergency exit on each floor giving access from either building to the other. The aggregate width of the two stairs would, however, have to be adequate for the total population of the two buildings, and, of course, the travel distance to a stair or horizontal exit should not exceed the figure already recommended.

CORRIDORS

287. The question of protection of corridors introduces problems in which fire protection requirements may conflict with practical considerations, particularly regarding the use of plain glass and the provision of opening fanlights for corridor ventilation.

288. The liability of ordinary sheet or plate glass to shatter under heat introduces the danger that, if partitions bounding corridors are glazed in this way, the glazing may cease to be a smoke stop before the occupants have had time to escape. The use of fire resisting glazing in suitable framing would generally obviate this danger, but it is recognized that this type of glazing may be considered objectionable in some cases from the point of view of appearance. It is, nevertheless, recommended that in partitions bounding corridors any glazing required should be in fire resisting glazing.

289. The use of opening fanlights for corridor ventilation is a matter of practical convenience which introduces a considerable risk from spread of smoke and hot gases. Dangerous smoke spread may occur from this cause even more readily than on account of the use of thin sheet glass. It is recommended that, even in occupancies where there is no sleeping risk, opening fanlights should, if possible, be avoided, and other means such as ducts should be adopted for providing any necessary ventilation of corridors. In occupancies involving a sleeping risk, opening fanlights should definitely not be used as they will increase the danger of smoke spread in the longer time interval which may elapse between the start of a fire and the evacuation of the building.

290. The subject of the fire resistance of partitions bounding corridors has already been dealt with in Section 1 of this Part of the Report, so far as it applies to buildings or parts of buildings in multiple tenancy. The principle adopted there was that partitions separating the various tenancies should have a fire resistance not less than the minimum recommended for the elements of structure of the building. This recommendation would determine the fire resistance requirements for partitions bounding corridors in cases where these partitions form a separation between tenants.

291. In buildings or parts of buildings which are in one tenancy, a distinction must be drawn between occupancies which involve a sleeping risk and those which do not. Where there is no sleeping risk, the essential requirement is that partitions should be capable of acting as a smoke stop for a reasonable length of time, and the temperature rise factor in the fire resistance definition can reasonably be disregarded. The use of very light combustible partitions should, however, be avoided and it is recommended that corridor partitions should be of such construction that they will not collapse nor allow flame penetration when subjected to the standard test conditions of B.S. 476 for half an hour. It is not considered necessary for the doors in these partitions to have any specific grade of fire resistance.

292. In occupancies where a sleeping risk has to be taken into account, it is recommended that corridor partitions should satisfy the full fire resistance requirements of B.S. 476 for half an hour, and doors in these partitions should preferably also have half an hour fire resistance. This would exclude the use of those types of light incombustible partitions which, though effective as smoke stops, would transmit heat comparatively rapidly. In occupancies such as offices, the use of these partitions is in many cases of great practical convenience and can reasonably be accepted, but in residential or institutional buildings this type of partitioning would introduce an excessive risk of the atmosphere in corridors becoming too hot to allow the safe passage of the occupants to the stairs.

PRECAUTIONS RELATING TO PERSONAL SAFETY

293. Attention is drawn to paragraph 179 where it is recommended that all partitions, *i.e.* not only corridor partitions, should be of incombustible material throughout, if the maximum travel distance of 150 ft. is to be adopted. Where combustible material is used in any partition, the figure would be restricted to 60 ft. These conditions are additional to the specific requirements for corridor partitions recommended above.

SURFACE FINISHES ON ESCAPE ROUTES

294. The danger to life from rapid flame spread on highly combustible linings has already been emphasized in Section 1. Certain recommendations were made there regarding the types of linings (classified according to the flame spread test of B.S. 476) which could be allowed in different types of occupancy. Escape passages were, however, excluded from these recommendations, and it is necessary to consider here the question of surface finishes on escape routes generally.

295. It is obvious that a higher standard of safety in respect of flame spread is necessary in corridors and staircases than in other parts of buildings. The escape routes should be passable for some time after the outbreak of fire, so that any material which is liable to spread fire in them should not be used. These routes also provide the readiest means of spreading hot gases through the building, and it is obviously undesirable that they should find readily combustible material in their immediate path. The danger arising from readily combustible linings on escape routes has been vividly demonstrated by recent American hotel fires in buildings which were fully protected structurally against collapse, but in which, nevertheless, there were large numbers of casualties. The presence of combustible linings on escape passages was one of the factors which contributed to these disasters.

296. It is recommended that except where special conditions operate, all surface finishes on walls, ceilings and soffits of stairs or escape routes should be incombustible.

DOORS

297. Doors are potential points of weakness in any scheme for means of escape. It is generally more difficult to get a specific grade of fire resistance in a fire check door than in an imperforate wall or partition. Also, even though the door leaves themselves may have an adequate fire resistance, it is not always possible to ensure that equally effective protection against the passage of flame, smoke and hot gases is provided round the edges of the door. This applies particularly to doors swinging both ways or in pairs. There is, besides, the inevitable danger from lack of presence of mind on the part of people who rush out of a room where there is a fire and leave the door open, thus allowing more rapid fire spread. The use of self-closing doors is an important precaution which must be considered from this point of view. The direction of opening of doors where there is any considerable number of people involved, is also a matter of importance.

298. Dealing first with the direction of opening, it is obvious that, ideally, all doors which may be used for escape should open in the direction of exit travel, so as to avoid the possibility of a door having to be opened against the pressure of a number of people trying to force a way out. Where there is only a small number of people in a room, however, this danger does not really arise (*e.g.* see *Factories Act*, 1937, *Section* 36 (2)—where a door is required to open out if there are more than 10 people in a room). In practice it may also be inconvenient in some cases for a door to open in the direction of exit travel, for instance, where a door opens

on to a corridor, although this particular difficulty may be overcome by forming a recess for the door. The matter of practical convenience cannot, of course, be allowed seriouly to prejudice life safety, and it is recommended that in all cases where the number of persons in a room or floor area exceeds 40, the doors serving it should, regardless of other considerations, swing in the direction of exit travel or both ways. All doors should open in the direction of exit travel also in buildings containing hazardous occupancies, as the possibility of rapid fire spread in these cases may make it essential to provide for the greatest possible freedom of movement in escape. Doors swinging both ways should be glazed with a panel of clear glazing to minimize risk of collision and where provided in fire-check doors this glazing should be fire resisting. Exit doors which have to be kept shut whilst the building is occupied should be fitted with panic bolts. If external to the building the working parts of such bolts should be of non-rusting metal. An exception to the rule given above can be made in the case of doors opening to the street which are kept locked back in the fully open position during the whole time the building is occupied by persons other than any resident staff. In such cases the doors may open inwards only.

299. The use of sliding doors, while not so satisfactory from an escape point of view as hinged doors, may be necessary in some cases, and can reasonably be allowed in such circumstances except in places of public entertainment. Where doors of this type are used on escape routes, they should be clearly marked on both sides, "Slide to Open."

300. Revolving doors should not be regarded as a means of escape. Where provided they should be supplemented by hinged doors of the required exit width immediately adjacent and this exit should be clearly marked.

301. It has already been indicated that self-closing doors provide a useful safeguard against fire spread, particularly against the spread of smoke and hot gases in the early stages of a fire. Doors of this type are primarily necessary for the protection of enclosed staircases, but where it is possible to adopt self-closing doors generally throughout a building, an added measure of life safety is provided. In this connection attention should be given to the possibility of using rising butt hinges, which provide a simple means of achieving this end and may be recommended for use on the front doors of flats.

302. Recommendations have already been made regarding the fire resistance of doors in staircase enclosures and corridor partitions. In the case of doors which swing both ways or in pairs there is inevitably a liability that smoke and hot gases may penetrate round the edges of the door leaves. Whilst this cannot be completely avoided it should be minimized by making the working clearances as small as possible. Reference should be made to B.S. 459 where a full description will be found of a type of fire-check door which will satisfy requirements where a door having a fire resistance of Grade E (half an hour) is necessary.

EXIT MARKING AND LIGHTING

303. It is essential, especially in buildings to which the public have access, or where numbers of people unfamiliar with the layout are admitted, to ensure that exits are well marked. Notices indicating the direction of egress should be provided where necessary. Doors which are required to be kept closed, or alternatively open, should have notices displayed to that effect. Corridors or staircases which are part of the means of escape but are not in frequent use should not be obstructed by storage or litter and should be marked accordingly. (See also *Factories Act*, 1937, *Section* 36 (6).)

304. Adequate artificial lighting should be provided to all staircases and exits. Special arrangements for marking and lighting of exits are essential in places of public entertainment and reference should be made to the Home Office *Manual of Safety Requirements in Theatres and Other Places of Public Entertainment*, or other applicable regulation.

MAINTENANCE

305. Careful maintenance of all the provisions for means of escape is a matter of great importance. This entails a regular inspection of all doors, passages and staircases, especially those not in regular use for normal traffic of the building. Attention should be paid to all door hangings and fastenings to ensure that the doors open readily.

306. Particular reference must be made to the necessity for proper maintenance of external escape facilities, *e.g.* external stairs or roof exits, in the construction of which iron, steel or wood are widely used. In view of their location they are particularly liable to corrosion or decay and may become unsafe. It is essential to guard against this by cleaning and painting at sufficiently frequent intervals, or by treating with other suitable preservative material. It would be an obvious advantage if such means of escape were constructed of materials less liable to require maintenance, and it is considered desirable that responsibility for such maintenance as may be necessary should be clearly defined.

PART IV. CHIMNEYS, FLUE PIPES AND HEARTHS

CHIMNEYS AND FLUE PIPES[1]

NATURE OF FIRE RISK

307. According to available records, amongst the highest proportion of fire calls are those concerned with chimney fires. Although the majority of these do not spread to other parts of the structure, a minority do so, often owing to defective construction, and in such cases are the cause of more serious fires. The extent of the risks involved is reflected significantly by the attention devoted to the problem in building codes and byelaws throughout the world. In this country progressive improvement in the standard of chimney construction has resulted from legislation, some of which has been enacted within comparatively recent years. Statistical evidence of any reduction in the extent or number of fires due to inadequate construction around the flue in buildings erected before and after the introduction of this legislation is not available, but general experience does suggest that a reduction has been achieved. Unfortunately there remain so many buildings erected with inadequate precautions that for some years to come many fires attributable to chimney defects can be expected.

308. A number of those which have occurred have been traced to the construction of chimneys in existing buildings, particularly older buildings. In many instances newer types of heating appliance have been installed and have created conditions more severe than those originally obtaining. The chimneys have then

[1] For the purpose of this Part of the Report, the term "chimney" has been used to denote the construction by means of which a flue is formed for the purpose of carrying the products of combustion from a heat producing appliance to the open air. This definition, of course, embraces the flue pipe which is in effect but a special form of chimney.

failed to provide sufficient insulation to adjacent timbers and in time fires have occurred. The incidence of these fires could doubtless be reduced considerably if thorough inspections of existing flues, particularly of domestic flues in older property, were carried out by competent persons before the installation of central heating, power or cooking plant or similar apparatus.

309. With the advent of non-traditional systems of construction, to which building byelaws now in force do not apply to the same extent as in the case of traditional construction, it becomes necessary to consider what standards of performance should be attained when these systems are applied to chimneys and flue pipes.

DESIGN OF CHIMNEYS

310. In the past the principal considerations which have controlled the design of chimneys have arisen from two major requirements. These are the need for strength and stability, and for protection against fire. Trial and error over a number of years have dictated the manner in which traditional chimney construction has satisfied these requirements and, as already indicated, existing byelaws largely framed upon them now provide a reasonable standard of security in respect of these factors. Until recently little attention has been paid to other factors which bear upon the design of chimneys.

311. The primary requirements of a chimney are to ensure efficient combustion of fuel and satisfactory removal of the products of combustion. These involve consideration of such additional factors as the flow of gases and questions of durability. Whilst in the design of larger industrial stacks draught conditions have usually been taken into account, the flow of gases in smaller flues of domestic size is only now receiving attention, mainly as a result of the need for more efficient burning of fuel. This need, together with consideration of factors involved in the application of non-traditional methods of building to the construction of flues, has drawn attention to problems of attack by acids on flue linings, disintegration of brickwork, and condensation, problems which, we understand, are the subject of research work at the present time.

312. In face of these many factors we have not been able to approach the subject in such a way as to stipulate all that is needed to design a chimney, for it is evident that a number of factors are outside the scope of our work. It has therefore been necessary for us to confine our attention strictly to the consideration of those conditions liable to create risk of outbreak of fire in surrounding parts of the building, and to recommendations for standards of performance which are desirable to ensure adequate protection against fire. It will be realized that this method of approach does not enable us to specify forms of construction incorporating various materials and methods of building. This will only be possible when all aspects of the subject have received due consideration.

313. We have found it necessary therefore to define rather carefully the scope of our study, and it has appeared to us necessary to limit it to:

1. The problem of preventing ignition of combustible material adjacent to the chimney under all conditions, including those arising in the course of a chimney fire and the discharge of hot gases and sparks from the chimney outlet.
2. Consideration of the appropriate fire resisting properties of materials suitable for chimney construction.

Many of the other factors to which we have referred, such as condensation and corrosion, do, however, have a bearing upon the degree of fire risk involved, since they influence the durability of materials and for that reason are liable to increase the fire hazard with lapse of time; but their origin and development and the means whereby their effects may be overcome are outside the scope of our study.

314. Since the major fire problem arises in domestic chimneys rather than in the large industrial stack, we have confined our attention mainly to chimneys and flues intended for use in conjunction with common heating installations. Chimneys for industrial plant are thus excluded except for a short reference to the application of the principles to such equipment.

FUNCTIONAL REQUIREMENTS

315. From experience it is known that, within the limits of our Terms of Reference, fires due to defective chimney design arise mainly from two causes:

1. The outer surface of the chimney becomes so heated that it ignites adjacent combustible material.
2. The materials of which the chimney is constructed are so affected by high temperature or the products of combustion that they disintegrate or corrode and allow leakage of sparks, soot and hot gases.

A third factor is the risk of ignition of combustible roof coverings or, where tiles, slates or other incombustible coverings are used, the risk of hot gases and sparks being blown under such coverings and into the roof space itself.

It follows therefore that the functional requirements with which we are concerned are:

1. The chimney must afford sufficient protection against hot flue gases to ensure that combustible material in adjacent parts of the structure both inside and outside the building is not heated to such a temperature that risk of ignition arises. This necessitates protection of combustible materials within the house and externally the provision of means whereby the products of combustion are discharged well clear of the roof.
2. The materials of which the chimney itself is made must be able to withstand the temperatures reached by the flue gases and other deleterious effects associated with the burning of fuel.

PROTECTION OF COMBUSTIBLE MATERIAL

316. In considering the first functional requirement, it is evident that there are two methods by which combustible material in the structure can be protected against the heat of the flue gases:

1. By constructing the chimney so that it has sufficient thermal insulation to ensure that the temperature of the outermost surface cannot reach a value liable to create any risk of igniting combustible material adjacent to or in contact with that surface.
2. By separating combustible material from the chimney by a space sufficient to ensure that the surface of adjacent combustible material is not heated to such a temperature that risk of decomposition or ignition arises.

INSULATION OF THE CHIMNEY

317. Under the first method the actual value of the limiting temperature on the outermost surface of the chimney should in principle be determined according to the ignition and combustion characteristics of the combustible material which may come into contact with that surface. Although characteristics vary for different classes of materials, for practical purposes it is necessary to decide on a single value which can be applied to all materials in common use. Wood and cellulosic

products, such as fibre-board, form by far the greater proportion of materials which have been used and might therefore be taken as the basis. However, the possibly more widespread use in future of other combustible materials calls for study of their ignition properties to determine whether they are more or less vulnerable than wood. For the present, it has only been possible to consider the problem in terms of timber.

318. Pilot ignition of timber occurs at a temperature of about 480° F. (250° C.), but exothermic decomposition begins at about 390° F. (200° C.), whilst at 212° F. (100° C.) slow distillation and decomposition occur. Since timber may be exposed continuously or at least for long periods, it is clear that the limiting value must be below 212° F. The fixing of the limit is to some extent arbitrary and we have adopted a temperature of 150° F. as the highest safe temperature which should be tolerated at the outermost surface of the chimney. Accordingly, it should be designed to ensure that this temperature is not exceeded and the thickness of the material surrounding the flue would, in principle, be determined on the basis of the normal flue gas temperature and the thermal conductivity of the material. Account must also be taken of the temperatures likely to be attained in the flue during a chimney fire or under conditions of flagrant misuse.

319. It should be noted that the temperature at the outer surface of a chimney will depend largely upon the manner in which it is finally incorporated within the structure. When incorporated so that it is exposed all round to the air the surface temperature may conform to the proposed standard. If, on the other hand, the outermost surface of the chimney is enclosed, for example by a wall lining, which may be of combustible material, the temperature of the surface will rise. To overcome this condition it is suggested that a clearance of not less than 1½ in. should be provided between the outer surface of a chimney and any adjacent combustible material forming part of such a lining. Moreover, combustible material in the adjoining structure of a building should not be allowed to come into contact with a chimney over any appreciable area, but exceptions may be made in the case of narrow widths of material such as skirtings, picture rails and narrow cornice moulds. If the chimney walls are formed of a material which is liable to structural damage the outer surface should be suitably protected.

320. The problem of durability is discussed in paragraphs 334-338 where attention is drawn to the risk of corrosion or disintegration of flue pipes or linings. If, as the result of such action, a flue pipe should become pervious to flue gases, flame or sparks, the safety of a building would depend largely on ability of the insulating material surrounding the flue to prevent communication of fire to any adjoining combustible material. There is, at the moment, no fire resistance test which is strictly applicable to chimney construction (the standard test for materials for flues, etc.—B.S. 476—is concerned with the suitability of a material as such rather than the fire resistance of a structure in which it is incorporated) but we consider that the standard fire resistance test for walls can be used as a basis for recommendations. We suggest that the fire resistance of any structure surrounding a flue or flue pipe should be equivalent to not less than two hours of the standard test. In addition, where a flue pipe is used there should be an air space between it and the surrounding fire resisting structure of sufficient width to permit access to the pipe for examination and repair (see also paragraph 338).

SPACE SEPARATION OF COMBUSTIBLE MATERIAL FROM THE CHIMNEY

Within Buildings

321. Whilst the insulation of chimneys should be regarded as the standard method of obtaining the desired protection, unprotected flue pipes are used, and since we are concerned with the application of principles, the principle

that combustible material must not be heated to an excessive temperature must apply equally to all types of chimneys, whether protected or not. The main use of unprotected flue pipes is in industrial buildings where they are confined mostly to single-storey buildings and independent stacks. In a more nearly domestic form they are also used in conjunction with heating appliances in single storey army huts, club rooms and similar institutions, and buildings of occasional assembly. A short length of unprotected pipe is also frequently used to connect a heating appliance to a main brick or masonry chimney.

322. Apart from any risk arising from the proximity of combustible material in the structure, the installation of an unprotected flue pipe in a multi-storey building creates risks arising from accumulation of dust or from the placing of combustible material in contact with it in the upper storeys, especially where these are in different tenancies. We recommend therefore that the use of an unprotected flue pipe should be restricted to the room in which the appliance connected to the pipe is situated, with the exception of special cases which may arise in industrial usage, *e.g.* flues leading from retorts in gasworks and which are in fact outside the scope of our consideration. Where a flue pipe passes through any other room or through a cupboard or an enclosed roof space it should be protected as described in paragraph 320.

323. The criterion of safety for an unprotected flue pipe is the safe temperature of adjacent combustible material, and we have considered 150° F. to be appropriate. Air space separation between pipe and combustible material must be sufficient to prevent the temperature of the latter exceeding this value. Unfortunately the data available which would assist us in framing recommendations for the practical implementation of the standard we propose are very limited.

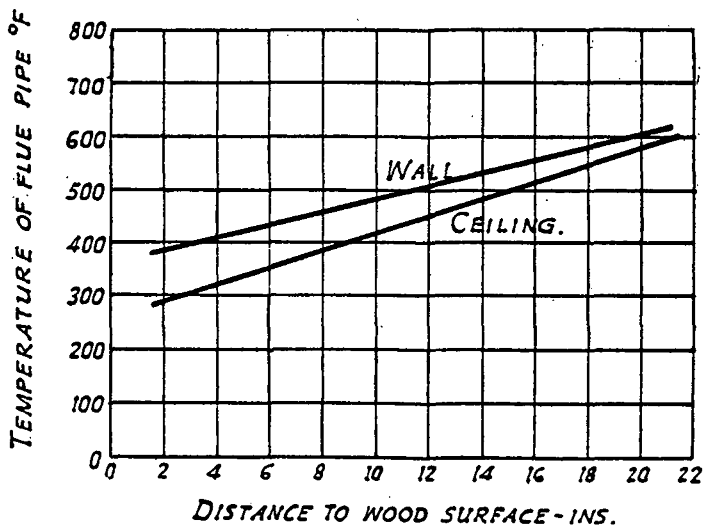


FIG. 10

SAFE DISTANCE OF A WOODEN SURFACE FROM AN UNPROTECTED 9 IN. DIA. BLACK IRON FLUE PIPE AT VARIOUS TEMPERATURES

(Underwriters' Laboratories Inc. of America—Bulletin of Research No. 27.)

324. Fig. 10, from a publication of the Underwriters' Laboratory of America, indicates the distance necessary between a wood surface and the surface of an unprotected vertical pipe to ensure that the surface temperature of the timber is not raised more than 90° F. above room temperature. The rapid increase in safe distance as the temperature rises is clearly indicated in the figure, but its application should be confined to the range of temperatures indicated. For instance, since it was compiled from data obtained after conditions had become stationary, *i.e.* after lapse of 2½ hours, it would be somewhat erroneous to infer directly, from an extrapolation of the curves, the conditions likely to arise in the course of a chimney fire which is normally of shorter duration.

325. Under the London County Council Byelaws, a distance of 9 in. is required between an unprotected flue pipe[1] and neighbouring combustible material, but under the Canadian Building Code, which was probably drawn up to meet conditions in which the use of combustible linings in the interior of buildings is more extensive, the minimum separation is 3 feet, with a reduction where it passes through a combustible roof structure. These wide discrepancies and the limited scope of the American research emphasize the need for further study.

Externally (Discharge from the Chimney Outlet)

326. Externally the degree of protection which may be afforded to combustible material used:

1. As roof coverings,
2. In other exposed parts of the building,
3. As part of the structure of a roof covered with incombustible materials,

will depend largely upon the height and distance at which products of combustion are discharged from the chimney outlet in relation to the position of these materials in the building fabric. Under present byelaws the chimney, excluding the pot, must be carried up to a minimum height of 3 ft. above the highest point of its junction with the roof.

327. This minimum height may not always be sufficient. Obviously the greatest risk arises when a material such as thatch, which is not fire retardant, is used as a roof covering, but even when fire retardant materials, such as tiles of slates, cover roofs of rather steep pitch, hot gases and sparks may be blown, under some wind conditions, along the roof slope and under the tiles and slates above the highest point of the chimney. Where a penthouse is built upon a flat roof, a nearby chimney may discharge unduly close to it. Again where a terrace is built on sloping land and the roof is stepped, the chimneys, built to the minimum 3 ft. height and according to their position, may discharge over the stepped walls and roofs immediately above. Even worse conditions may arise in the case of chimneys from single-storey outbuildings discharging near to the wall face of a multi-storeyed main building.

328. The essential precaution is to ensure that combustible material forming part of the building fabric is far enough from the outlet of a chimney to prevent ignition by flames, sparks or hot gases.

Under the Canadian Building Code, in addition to a minimum height of 3 ft. above the highest point of junction with the roof, every chimney must be at least 2 ft. higher than any ridge, parapet wall or roof structure[2] within 10 ft. of it. This may be a somewhat onerous requirement, and in the light of the evidence

[1] Such a flue pipe can only be used inside a building within the room in which the appliance to which it is connected is situated.

[2] Included amongst roof structures in the Code are penthouses, bulkheads, towers and belfries.

which we have been able to review we recommend that, in addition to the minimum height required by the byelaws, the outlet of a flue from a normal domestic appliance in a residential building having a fire retardant roof covering should be at least 7 ft. 6 in. in a horizontal plane from the roof or any structure built upon the roof, or at least 2 ft. higher than any ridge within 7 ft. 6 in. of it. For other buildings in which larger heating or cooking appliances are customarily installed, the corresponding dimensions should be 10 ft. and 3 ft. If the roof covering is not fire retardant we recommend that no flue outlet should be lower than the ridge or highest point of the roof, or less than 3 ft. above any ridge within 7 ft. 6 in. of it. Industrial chimneys and stacks to which the general principle equally applies, will normally require individual consideration.

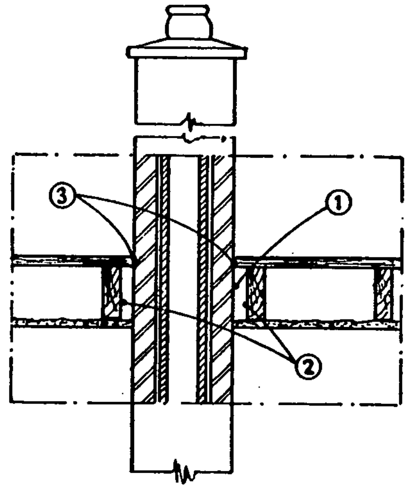
FLUE GAS TEMPERATURES AND TESTS

329. To determine what thickness of insulation, having a specific thermal resistivity, is required around a flue, or how far combustible material should be spaced from the flue in order to comply with the conditions which we have recommended, it is necessary to know the temperatures likely to be attained by the outer surface of the flue under the most severe conditions of use. Attention has already been drawn to the importance of taking into account the temperatures likely to be attained during a chimney fire. Of equal significance are the high flue gas temperatures, as high as 1850° F., which have been recorded with some slow combustion stoves when timber or free burning high volatile coal has been burned in them under forced draught conditions; such temperatures, although perhaps not so high as those which may be attained in the case of a soot burnout or chimney fire, may persist for a relatively longer period.

330. Fig. 11 (from a Bulletin of the U.S. Bureau of Standards) shows the temperature rise which may be experienced at critical points in the structure of a chimney when subjected to different flue gas temperatures reaching a maximum of 1200° to 1300° F. for an hour or more. The effect of high flue gas temperatures, especially in the case of unlined flues, will be realized from the curves, and the possibility of dangerous conditions being created merits special attention. Since the data on high temperatures arising under severe conditions of use and those appertaining to chimney fires are very limited, it is not at present possible to specify precisely what are the worst conditions from the fire protection aspect. When this deficiency is made good, it will still be necessary to determine a suitable time-temperature curve, analogous to the standard curve defined in B.S. 476, against which chimneys may be tested from the point of view of adequate thickness of insulating material and the required spacing of combustible material in the adjacent structure.

MATERIALS AND TESTS

331. The resistance of materials to high temperature is implicit in the second functional requirement concerning their suitability for incorporation in chimney structures. It is but one aspect of the broader problem of durability to which we refer later. At present the standard tests for materials for flues, furnace casings, hearths and similar purposes are defined in B.S. 476. Unfortunately many of them do not appear to us to provide an adequate means of determining the suitability of materials. For example, the strength test is required to be made on square prisms of material and the thermal conductivity standard demands a conductivity of not more than 20 B.Th.U. per sq. ft. per hr. per °F. per in. thickness which would exclude iron and steel.



CHIMNEY CONSTRUCTED OF CLAY BRICKS 4" THICK. FLUE DIA. APPROX. 9". TIMBER JOISTS SPACED 2" AWAY FROM OUTER SURFACE (POINT 2).

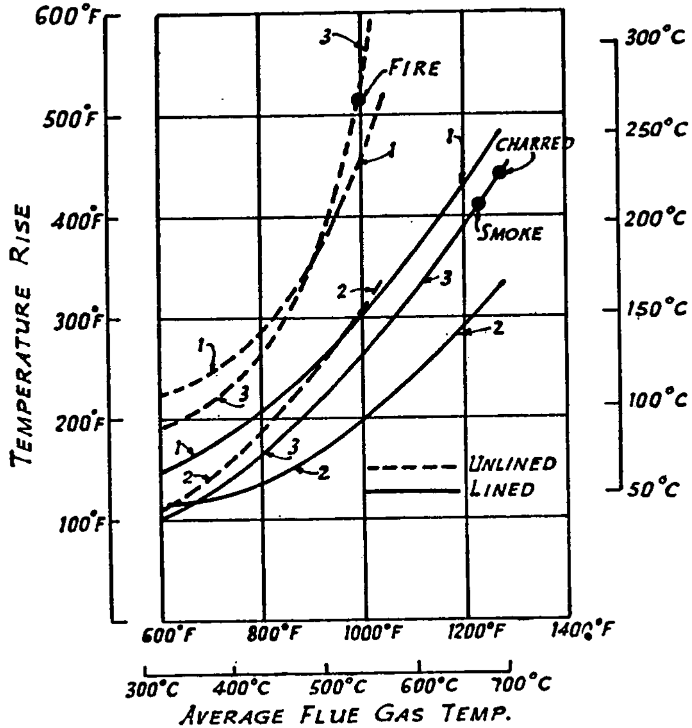


FIG. 11

TESTS ON BRICK CHIMNEYS, LINED AND UNLINED

(U.S. Bureau of Standards.)

332. Perhaps the most advantageous test would be one analogous to that devised to determine the fire resistance of elements of structure, and it should therefore be made on actual sections of the chimney as proposed for installation in a building structure. Lack of data again prevents our considering the exact nature of the test, but we would strongly urge that investigations should proceed with the object of establishing appropriate criteria. Naturally it would be necessary to take account of factors other than that with which we are mainly concerned, *i.e.* resistance to high temperatures, and possibly a series of tests would be necessary.

333. Materials used in chimney construction should of course be incombustible. The present standard of incombustibility in this country is that defined in B.S. 476: 1932. Recent American work, in which the specimen was suddenly exposed to a high temperature instead of being subjected to gradual heating up as required in the B.S. test, showed that materials classed as incombustible in accordance with B.S. 476 could be induced to flare or burn on sudden exposure to high temperature. Such materials are those containing a very low proportion of combustible impurities, *e.g.* asbestos lagging. It seems desirable therefore that the procedure used in the B.S. tests should be examined to determine whether its application to materials used for chimney construction might not call for modification.

DURABILITY

334. In the course of this Part of our Report we have made several references to durability. This is a factor affecting the life of materials and of the structure in which they are incorporated. It is therefore our concern inasmuch as it is relevant to the continued fire protection of buildings quite apart from other structural and economic aspects.

335. A material may be resistant to high temperature for a short while or over a comparatively long period. It may be susceptible to the abrasive effect of regular cleansing or it may suffer through gradual disintegration or corrosion as a result of the continued chemical action of acid constituents of the flue gases. Corrosion of metal flue pipes and disintegration of brickwork and fireclay or other lining materials are common phenomena. Due largely to condensation in the presence of acids which may cause deposit or sulphates, particularly at bends in the chimney, they may be accompanied by gradual accumulation of soot, consequent interruption of efficient exhaust and eventual leakage of sparks, smoke and hot gases.

In this respect we would draw attention to the gradual failure of internal linings when used in conjunction with certain types of heating appliances which give rise to conditions more severe than is customary in the case of open fires.

336. Although regular cleansing of a chimney is not in itself a mandatory requirement, cleansing becomes almost obligatory as the user may be liable to prosecution if the chimney catches fire. Methods commonly employed vary in different parts of the country. The abrasive action of some methods used may aggravate incidence of fire in brick or stone chimneys by encouraging accumulation of soot. In general, however, proper rendering, pargetting or the incorporation of fireclay or stoneware linings has proved sufficient protection against abrasion. Following the incorporation of flue pipes in dwellings, particularly in view of the deleterious effects, cumulative with lapse of time, to which some of these pipes may be subject, methods of cleansing and the implements used might well be reviewed; local practice in some areas may need radical revision if such flue pipes are not to be seriously damaged.

337. An allied aspect is that of heat shock, to which certain types of pipe materials and their finishes are susceptible, which may lead to cracking or spalling and exposure of materials unsuited to withstand high temperatures with ultimate

failure of the chimney structure. The functional requirements which we have specified imply that the materials forming the flue, including its insulation, must be durable throughout the life of the building. Any impairment of the satisfactory performance of the flue would result in a complete failure to satisfy these requirements.

338. It is therefore important that where the construction is such as to be at all susceptible, facilities for inspection, repair or replacement should be afforded at suitable intervals, according to the anticipated life of the materials and conditions of their use, and be conveniently arranged in the structure. What may be regarded as a reasonable life for a chimney structure is a further matter for investigation from the economic, structural and fire protection aspects.

HEARTHS

NATURE OF FIRE RISK

339. Fires which have involved damage to buildings due to defects in hearths may be attributed mainly to:

1. Defects in older property built before present byelaws were enacted.
2. Faulty workmanship and non-compliance with byelaws.
3. Installation of newer heating appliances in older property in such a way that existing hearths no longer protect adjacent combustible material from the increased heat transmission.

Statistical evidence indicates that such fires are more numerous than those due to chimneys. Whereas the chimney has other functions to perform than that of protecting adjacent combustible material from the effects of heat, the hearth functions solely as a protective element of the structure.

FUNCTIONAL REQUIREMENTS

340. The functional requirements of a hearth are to prevent:

1. The deleterious effect upon and risk of ignition of adjacent combustible material and deleterious effect upon metal in the surrounding fabric of the building by heat conducted from the fire.
2. The ignition of adjacent combustible material by radiated heat or burning fuel falling from the fire.

The hearth must therefore be constructed of incombustible material, and should afford sufficient insulation against thermal transmission between an appliance and any adjacent combustible material or metal and be of such a shape, as regards thickness, width, projection and the height of its kerb, that no risk of ignition of adjacent combustible material can arise.

PROTECTION OF COMBUSTIBLE MATERIAL

341. We consider that the surface temperature of combustible material adjacent to the hearth should not exceed 150° F. (see paragraph 318) as a result of thermal transmission or radiation of heat from the fire.

342. Existing byelaws, having the principal object of preventing concealed timber from being placed too near the fireplace opening, specify requirements for the construction, thickness, width and projection of domestic hearths, and have achieved a reasonable measure of protection as regards those laid level with the floor. Nevertheless, since the byelaw projection is measured from the front of the fireplace opening, dangerous conditions have sometimes been created by the installation of a fire container considerably in advance of this opening.

343. It is customary for the householder to provide a fender or kerb to protect his furnishings and combustible material in the floor against ignition by burning fuel falling from the fire. Whilst risks may arise as a result of omission, we consider that it would be onerous to require the kerb to be formed as part of the structure of the hearth. Loose kerbs, which permit of latitude in the design and use of materials and have the additional advantage over fixed kerbs of providing easy access for cleaning, have provided reasonable protection; but in order to ensure adequacy of protection of all kerbs, fixed or detachable, we recommend that they should be at least 1 in. high when used in conjunction with well fires or other low seated appliances and not less than 2 in. high where basket fires or appliances with raised fire containers are installed. Fixed kerbs which may at times be subject to rough usage and abrasion should be at least 2 in. wide and we further recommend that no firegrate or other open appliance designed to burn fuel under exposed conditions should be installed so that its front is less than 14 in. from the inside of the kerb.

344. In making these recommendations we are aware that some authorities have incorporated relaxations in their requirements for hearths below closed slow combustion ovens, stoves and the like. Since there is a wide variety of these appliances, we feel unable to make specific recommendations, and prefer that each type should be considered upon its merits from the point of view of the protection it affords against burning fuel falling out of the stove. We are also aware that a tile-slabbed fire surround and firegrate together with a tiled hearth is frequently manufactured and supplied as a single unit of equipment and is commonly installed in a fireplace opening upon a hearth constructed in accordance with byelaw requirements. Although the superimposed tiled hearth, particularly if it incorporates a kerb, may provide additional protection against heat radiated from the appliance, we consider that any reduction in the distance which we have recommended between the front of the appliance and the kerb could only lead to increased hazard due to the risk of burning fuel falling from the appliance. Hearths which have a sloping or curved surface to assist radiation of heat from an appliance may be designed in such a way that adjacent combustible materials are fully protected, and at the same time incorporate adequate protection of these materials against thermal transmission of heat, but again suitable precautions must be incorporated against risks from falling fuel.

345. To overcome difficulties which arise in the construction of some non-traditional houses where continuity of a structural framework is essential, the hearth is often laid above floor level upon timber or composite joists, *e.g.* timber and steel, or timber and concrete. Where one of these joists passes close to the chimney wall below the fireplace opening, the byelaw thickness of hearth may not afford sufficient insulation against thermal transmission of heat from all types of appliance. Unfortunately lack of data precludes our making specific recommendations, but at least the byelaw requirement that combustible material should not be placed within 10 in. of the upper surface of the hearth, which is at present limited to timber and woodwork placed directly under the fireplace opening, should be extended to prevent joists from being so hazardously placed beneath hearths.

PROTECTION OF INCOMBUSTIBLE MATERIAL

346. Under existing byelaws it is presumed that domestic hearths may be supported upon combustible bearers, but in some non-traditional forms of construction their supports are of metal or reinforced concrete. It might appear that where combustible material is largely excluded from the structure considerable relaxation of the customary requirements should be permitted. Such construction, however, poses a further problem, *i.e.* the insulation of metal in the

structure from the weakening effect of continual exposure to high temperature. It is known for instance that the breaking strength of mild steel, loaded continuously over a period of weeks or months at high temperature, is much lower than that indicated by a normal short time test. Much depends upon the composition of the metal, but typical is a mild steel having a short period ultimate tensile strength of 21 tons per sq. in. at 450° C. which was found to fail under a stress of about 10 tons per sq. in. maintained continuously for some 25 days at this temperature. Although, even with the most elementary precautions, such high temperatures may never be realized in domestic structures, and the effect diminishes at lower temperatures, they may well occur in some conditions of industrial building where they will obviously require special consideration. Corresponding effects occur at much lower temperatures in the case of aluminium alloys. The ultimate strength of many forms of light alloy is reduced even in a short period test to the normal working stress by exposure to a temperature of little more than 200° C. When continually exposed for longer periods, much lower stresses only can be borne.

347. Information sufficient to make precise recommendations is not available, but we consider it undesirable to suggest any relaxation of the standard which we have recommended in the case of timber, *i.e.* that the temperature of adjacent material should not exceed 150° F. in view of the following factors:

1. The conduction of heat along metal for a considerable distance from an appliance and the likelihood of exposure of combustible material some distance away to temperatures higher than those we recommend.
2. The combustible nature of the majority of floor finishes suitable for use in domestic buildings and the customary presence of combustible furnishings close to the hearth.

Individual consideration based upon the principles we have suggested will be necessary in industrial practice and some relaxation may well be appropriate in special cases.

MATERIALS FOR CONSTRUCTION OF HEARTHS

348. Materials used in the construction of hearths should possess the same properties as those required of chimney materials and, in the light of past experience, we would emphasize that in any case none should be combustible.

PROBLEMS OF ASSEMBLAGE

349. Our study has indicated the need, from the fire protection standpoint, for considering the chimney or flue pipe, appliance and hearth as a whole rather than as independent units. Nevertheless, in the course of the life of a building it may ultimately become desirable or, indeed, necessary to replace one element of the assemblage by another of a different pattern. As we have indicated in paragraph 308, changes of this description may lead to dangerous conditions, particularly if at the outset the fire protection recommendations which we have outlined were only just satisfied. From the point of view of safety from fire it might therefore be considered preferable to anticipate the worst conditions likely to arise as a result of such changes, thus ensuring a measure of safety whatever combination of elements might be used. Such a procedure, however, involving a maximum of protection, would undermine the fundamental need for making the most efficient use of the assemblage as a whole from the point of view of generation of heat and conservation of fuel.

350. It is evident that a primary concern of any further study should be the reconciling of these two apparently opposed aspects in conjunction with the economic and structural factors involved. Since more efficient heating systems

must become established features in new dwellings, the need for such a study is quite apparent, and since the appliance is the primary element of every heating system, it would be helpful if facilities could be arranged whereby proposed methods of installation could be tested from the fire protection aspect. This in turn would enable manufacturers to issue recommendations for the installation of their appliances which take full account of the fire risks involved.

351. In considering domestic fireplaces we have referred to the fire protection afforded by the hearth and kerb, however formed, as complementary parts of a single element. In the framing of regulations to which both the modernization of existing buildings and the construction of new ones must conform, it may be desirable however to regard items commonly manufactured, such as slabbed hearths, as distinct from hearths which must in any case be incorporated in the building structure. Similarly it may be advantageous to consider the requirements of kerbs independently of those of hearths.

ADDENDUM TO PART I. WOOD SHINGLES AND TRANSPARENT PLASTICS

Since Part I of our Report was completed some matters have been raised which properly relate to that Part. One of these concerns the use of wood shingles on roofs, and is the outcome of a request by the Timber Development Association that we should give further consideration to our statements in Part I. Another concerns a proposal to use combustible transparent plastics in roof lights and windows. Our conclusions on these matters are given below. In addition, some fire statistics for the year 1946 will be found in Appendix III.

WOOD SHINGLES FOR ROOFS

The Timber Development Association[1] has submitted to us a considerable body of evidence (including a 64-page brief prepared by the Red Cedar Shingle Association of British Columbia), which a deputation from the Association presented to our Working Group on 7th July, 1947. A series of demonstrations was arranged by the Association to show the behaviour of wood shingles towards various sources of ignition, and a film in amplification thereof was shown. We have had collated for us much evidence on the conditions under which shingles are used in other countries, and have studied the American records issued mainly by the National Fire Protection Association, which formed the basis of our original views, in the light of objections to this evidence furnished by the Association. On the more scientific aspects we have considered the principles underlying the ignition and burning of timber, such data as are available on comparative characteristics of timbers in their behaviour at high temperatures, and the recent studies on radiation from building fires. We believe, in fact, that we have covered all the evidence which is available.

The Association in their summarized statement put forward for our consideration the following proposal to govern the use of red cedar shingles in this country:

> "It is recommended that shingle roofs of approved standards be permitted on detached buildings, and on attached buildings up to four in a block, subject to a distance requirement of 8 ft. between one habitable building or block and the next when adjoining buildings or blocks have shingle roofs, but there shall be no distance requirement when at least alternate buildings or blocks have roofs of slate, tile or equally fire retardant material."

This proposal is a complete departure from existing standards in this country,

[1] Where the term "Association" is used subsequently without qualification it refers to the Timber Development Association.

and a considerable relaxation from requirements in many American codes. We are unable to agree to it and would mention here two basic factors which have led us to this decision:

1. We are not convinced by the available evidence that there is any material difference between the inflammability of the various types of wood shingle roof and methods of fixing them under conditions of potential conflagration. Shingle roofs of slash grain shingles are admitted to present a hazard.
2. In our opinion the type of development suggested in the recommendation of the Association for buildings with wood shingle roofs if built up to present day maximum densities would possess a serious conflagration hazard, especially in dry, hot weather.

The most which we feel able to do at this stage is to give some interpretation of our original statements particularly of the term "isolated building," by which we mean a building separated from its neighbours by a distance sufficient to reduce the exposure hazard to a reasonable proportion. There is a considerable practical difficulty in defining for this purpose the term "isolated building," for what we should consider an "isolated building" in an area where slate, tile or other fire retardant roofs predominate,[1] could not be considered "isolated" in an area where all or most of the roofs were of wood shingles.

Where fire retardant roofs predominate we are prepared to consider as an "isolated building":

> A building or block (consisting in the case of dwelling houses of not more than two houses), not exceeding 36,000 cu. ft. in capacity and two storeys in height built not less than twice its height or 40 ft. (whichever is the greater), from the boundary of the site or from any other building and limited to occupancies of low normal fire load.

Apart from its effectiveness in minimizing the risk of spread of fire, a separation determined as above would have in this country the further effect of limiting the number of houses which are covered with roofs of wood shingles, simply because the cost of the additional land would be prohibitive. Such a limitation in number would be an additional safeguard. However, in dealing with the matter on technical grounds of fire protection it is necessary to consider to what extent such a separation would be effective in an area where this secondary factor would not operate and where shingle roofs might therefore be used on a large number of houses.

We can give no assurance that it would be so, and as it is not possible to set down in simple terms the conditions under which the use of shingles could then be considered satisfactory, it must be left that any such case should be considered as it arises. The separation would depend on both the number and distribution of the buildings and would need to be greater than that quoted above.

We have elaborated this latter feature in view of the reference in the Association's statement to "the inconsistency displayed by the Committee in reference to the relative fire hazard of thatch and wood shingles." There is no inconsistency, for whilst we assumed that thatch would not be used on any large scale, wood shingles provide a type of roof which is well adapted for large scale use. There arises therefore a need for further precautions, *e.g.* limitation in number, a factor which we felt would probably never arise with thatch. If in future there were any

[1] Even under these conditions a further difficulty arises in that the risk will be influenced by the height and size of the adjacent buildings. Thus a separation adequate in relation to adjacent small buildings could not be considered adequate if the adjacent buildings were of considerable height and size. There is no simple means of dealing with this difficulty in practice other than by complete prohibition of shingles in such areas, *e.g.* by a system of fire-zoning to which we referred in Part I of our Report and which is adopted in most American codes. In view of the cost of land in such highly developed areas it is doubtful whether the necessary open space would be reserved from building.

appreciable increase in the use of thatch it would be necessary to consider whether further precautions would be needed. When considering precautions in general it is necessary to take account not only of the inherent risk of the construction or material, but also the frequency with which that risk is likely to arise.

We wish to express our appreciation of the facilities granted to us by Chief Officer Pratten of the London Salvage Corps for observing the demonstrations made by the Association, and to the Association itself for the concise manner in which their deputation presented the very considerable body of evidence.

USE OF COMBUSTIBLE TRANSPARENT PLASTICS IN ROOF LIGHTS AND WINDOWS

Transparent plastics which were used during the war, notably in aeroplane construction, have become available for use in building and we have been asked to consider their use as an alternative to glass in roof lights and windows from the fire protection standpoint. A particular advantage claimed for one of these materials was that being made in sheets corresponding in size and pitch of corrugation to corrugated asbestos cement or galvanized steel sheeting, it could be substituted directly for those materials both in walls and roofs without special provision for fixing necessary in the case of ordinary glazing.

In view of the fact that most plastics are combustible and the transparent varieties at present available are no exception to this rule, the proposal introduced fire problems not previously encountered because glass, the only material previously available, is incombustible.

We asked that a demonstration should be arranged of the behaviour of such a plastic when used as a roof light, under the effect of a brand. The plastic ignited and continued to burn readily but it appeared that the major hazard consisted in the falling of molten and flaming drops of the material into the building below. The Joint Fire Research Organization undertook at our request tests on the ignitability of the same transparent plastic. After full consideration of the results of this work and of the risks involved we concluded that from the point of view of fire risk in buildings we could not recommend its use in any circumstances on the roofs of buildings, nor as an alternative to glass in windows.

Our observations relate to materials falling into Classes III and IV of the spread of flame classification (B.S. 476). No transparent plastic falling into Class I or II has come to our notice. Should they be developed they will need further consideration.

We wish to draw attention to the fact that corrugated glass sheets were manufactured before the war. If the ease of fixing is so important a factor we would urge that the production should be restarted.

C. Roland Woods, *Chairman*
J. W. Berry
E. L. Bird
L. N. Duguid
F. H. Durant
F. W. Jackson
A. J. Makins
E. A. Oliver
G. T. Pound
W. J. Richardson
J. A. Rogans
W. L. Scott *
H. E. Skillern
Digby L. Solomon
Guy Symonds *
Sydney Tatchell
W. E. Thorowgood
W. H. Tuckey
W. H. Way
J. West
R. C. Bevan, *Secretary*

* Since deceased.

1st December 1949.

APPENDIX I

DATA ON RATE OF MOVEMENT OF PEOPLE IN EXITS

FACTORIES ACT, 1937 *

	LOCATION	TYPE OF EXIT	DIRECTION OF TRAVEL	EXIT WIDTH Units of 22″	STAIR HEIGHT	NO. OF PERSONS PER UNIT WIDTH PER MINUTE	REMARKS
1	Railway Stn.	Gateway		2		28	Open doorway
2	Retail Store	Pair of swing doors		3		34	Doors fixed open
3	Theatre, Stalls Exit	Double swing doors		4		30	Doors not fixed open
4	Factory, Ground floor	Single door		2		47	Fire drill
5	Railway Stn.	Stair	Up	4	19 ft.	32	Passengers leaving Stn.
6	Office Bldg.	do.	Down	4	10 ft.	37	Fire drill
7	Theatre	do.	do.	3	15 ft.	32	Normal emptying conditions
8	Govt. Offices	do.	do.	2	20 ft.	29	Persons leaving office

* *Means of Escape in Case of Fire—Memorandum for the Guidance of Local Authorities as to the granting of Certificates under Section* 34 *of the Act.*

FRENCH TESTS—1945

	LOCATION	TYPE OF EXIT	DIRECTION OF TRAVEL	EXIT WIDTH	STAIR HEIGHT	NO. OF PERSONS PER UNIT WIDTH PER MINUTE	REMARKS
9	Test Corridor between counters in Shop			1 m. 80 (5′ 11″)		37	Normal speed
10	do.			do.		80	Intermediate speed
11	do.			do.		119	High speed
12	Staircase in Shop		Down	Stairs 2 m. 08 (6′ 10″)		30	Normal speed
13	do.		do.	Landing 1 m. 80 (5′ 11″)		46	High speed
14	do.		do.	1 m. 12 (3′ 8″)		Av. 37	Normal speed
15	do.		do.	do.		Av. 70	High speed

APPENDIX I

French Tests—Published 1938

	LOCATION	TYPE OF EXIT	DIRECTION OF TRAVEL	EXIT WIDTH	STAIR HEIGHT	NO. OF PERSONS PER UNIT WIDTH PER MINUTE	REMARKS
16	Horizontal Opening			1 m. (3′ 3″)		91	Normal walking pace
17	do.			3 m. (9′ 10″)		72	do.
18	do.			1 m.		128	Hurried without pushing
19	do.			3 m.		119	do.
20	do.			1 m.		168	Hurried and pushing
21	do.			3 m.		171	do.
22	Staircase		Up	1 m.		45	Normal walking pace
23	do.		do.	3 m.		51	do.
24	do.		do.	1 m.		73	Hurried without pushing
25	do.		do.	3 m.		82	do.
26	do.		do.	1 m.		94	Hurried and pushing
27	do.		do.	3 m.		107	do.
28	do.		Down	1 m.		52	Normal walking pace
29	do.		do.	3 m.		56	do.
30	do.		do.	1 m.		80	Hurried without pushing
31	do.		do.	3 m.		77	do.
32	do.		do.	1 m.		89	Hurried and pushing
33	do.		do.	3 m.		82	do.

AMERICAN TESTS QUOTED BY U.S. BUREAU OF STANDARDS *

	LOCATION	TYPE OF EXIT	DIRECTION OF TRAVEL	EXIT WIDTH	STAIR HEIGHT	NO. OF PERSONS PER UNIT WIDTH PER MINUTE	REMARKS
34	Railway Stn. Illinois Central Rrd.	Double swing door		6′ 0″		34	
35	do.	Single swing door		3′ 0″		45	Same door as above but one leaf locked
36	do.	Passageway		8′ 0″		49	
37	do.	Ramp		8′ 0″		47	
38	do.	Stair	Up	8′ 0″	17′ 5″	31	
39	do.	do.	do.	4′ 3″	14′ 0″	31	
40	do.	do.	Down	5′ 6″	11′ 8″	33	
41	do.	do.	do.	4′ 0″	11′ 8″	51	

* U.8. Bureau of Standards: *Design and Construction of Building Exits.*

APPENDIX I

Tests on Stairs Carried Out by U.S. Bureau of Standards *

	Location	Type of Exit	Direction of Travel	Exit Width	Stair Height	No. of Persons per Unit Width per Minute		Remarks
						Av.	Max.	
42	Railway Stn. Grand Central Terminal	Stair	Up	8′ 1″	18′ 9″	21	28	
43	do.	do.	do.	5′ 0″	14′ 4″	31	42	
44	Office Bldg. U.S. Bureau of Stds.	do.	do.	3′ 0″	13′ 5″	51	51	Controlled test
45	Office Bldg. U.S. Census	do.	Down	7′ 3½″	10′ 3½″	40	42	Fire drill
46	do.	do.	do.	7′ 2½″	10′ 3½″	24	31	do.
47	Theatre. 44th St. Theatre, N.Y.	do.	do.	6′ 3″	15′ 0″	19	23	
48	Subway. 34th St. and 7th Av. N.Y.	do.	do.	6′ 0″		30	31	
49	Office Bldg. U.S. Census	do.	do.	5′ 6″		24	30	Fire drill
50	Railway Stn. Grand Central Terminal	do.	do.	5′ 0″	14′ 4″	33	49	
51	Office Bldg. U.S. Civ. Serv. Comm.	do.	do.	4′ 1½″	13′ 1½″	30	32	Fire drill
52	Office Bldg. U.S. Census	do.	do.	4′ 0″	20′ 7″	23	25	
53	Office Bldg. Nat. Bureau of Stds.	do.	do.	3′ 0″	13′ 5″	54	60	Controlled test

* U.S. Bureau of Standards: *Design and Construction of Building Exits.*

TESTS ON DOORWAYS AND RAMPS CARRIED OUT BY U.S. BUREAU OF STANDARDS *

	LOCATION	TYPE OF EXIT	DIRECTION OF TRAVEL	EXIT WIDTH	STAIR HEIGHT	NO. OF PERSONS PER UNIT WIDTH PER MINUTE		REMARKS
						Av.	Max.	
54	Circus Ground	Gateway		12′ 0″		25	28	
55	Railway Stn. Grand Central Terminal	do.		6′ 6″		40	47	
56	Office Bldg. U.S. Veterans' Bureau	Pair swinging doors		6′ 0″		23	31	Fastened open
57	Department Store	do.		5′ 8″		25	35	do.
58	Office Bldg. U.S. Bureau of Printing	do.		5′ 6″		35	45	do.
59	Office Bldg. Nat. Geographic Soc.	do.		5′ 4″		28	31	Both leaves open
60	do.	do.		2′ 8″		38	45	One leaf shut
61	Office Bldg. U.S. Dept. of Commerce	do.		5′ 4″		26	30	Fastened open
62	Railway Stn. Grand Central Terminal	Gateway		5′ 0″		42	45	
63	do.	do.		5′ 0″		52	58	
64	Office Bldg. U.S. Census	Pair swinging doors		5′ 0″		38	53	Fastened open for fire drill
65	do.	do.		5′ 0″		30	35	do.
66	Department Store	Revolving door		3′ 6″		19	21	Disch. rate based on width of single leaf
67	Office Bldg. U.S. Treasury	Swinging door		3′ 1″		28	37	Fastened open
68	Office Bldg. U.S. Govt. Printing	Revolving door		2′ 1″		38	58	Leaves of door collapsed leaving 2′ 1″ opening each side
69	Railway Stn. Grand Central Terminal	Ramp	Up	6′ 4½″	Slope in 9·7	37	40	
70	do.	do.	Down	6′ 4½″	do.	26	37	
71	do.	do.	do.	6′ 4½″	do.	33	38	

* U.S. Bureau of Standards: *Design and Construction of Building Exits.*

APPENDIX II

METROPOLITAN POLICE TESTS—CROWDS LEAVING FOOTBALL GROUNDS

	LOCATION	TYPE OF EXIT	DIRECTION OF TRAVEL	EXIT WIDTH	STAIR HEIGHT	NO. OF PERSONS PER UNIT WIDTH PER MINUTE	REMARKS
72	Chelsea Ground	Gateway		6′ 0″		Av. 48	
73	Fulham do.	do.		6′ 0″		Av. 50	
74	do.	do.		6′ 0″		Av. 64	Downward gradient towards exit gates
75	Arsenal do.	do.		24′ 4″		Av. 46	Width subdivided into 4 lanes

APPENDIX II

DETERMINATION OF STAIRCASE WIDTH

CALCULATION OF DISCHARGE VALUE

The values given in Table 9 of Part III (page 89) are based on the following assumptions:

(i) Rate of flow through an exit is 40 persons per unit width per minute.

(ii) Each storey of the building is evacuated on to the stairs in not more than 2½ minutes.

(iii) There is the same number of people on each storey.

(iv) Evacuation occurs simultaneously and uniformly from each storey.

(v) In moving at a rate of 40 persons per unit width per minute, a staircase can accommodate one person per unit width on alternate stair treads and one person on each 3 sq. ft. of landing space.

(vi) The storey height is 10 ft.

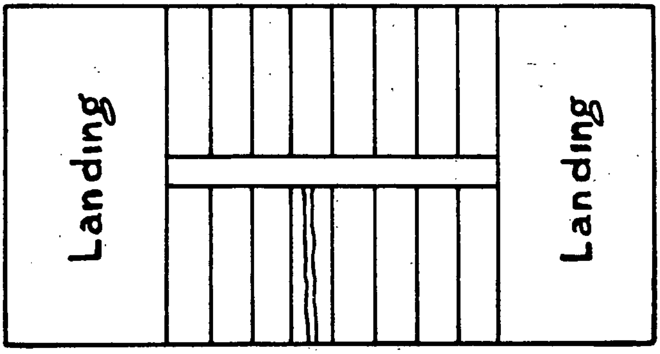
(vii) The exits from the floors to the stairs are the same width as the stairs.

(viii) People leaving the upper floors are not obstructed at the ground floor exit by persons leaving the ground floor.

To illustrate the method of determining the figures in Table 9 consider a single staircase 3 ft. 6 in. (2 units) wide serving a building having two storeys above the ground storey. From Fig. 12 it will be noted that a 10 ft. storey height of a 3 ft. 6 in. wide stairs will accommodate 34 persons under the conditions set out in assumption (v).

The rate of flow through the two-unit exit from each floor on to the stairs will be 80 persons per minute. It will therefore take 34/80 mins. for the staircase to fill to capacity $=\cdot 4$ minutes (24 secs.).

After this period the rate of flow on to the stairs will be determined by the rate at which persons leave the street exit, *i.e.* again 80 persons per minute. Hence from each of the two floors the flow will be $\frac{80}{2}=40$ persons per minute. Since

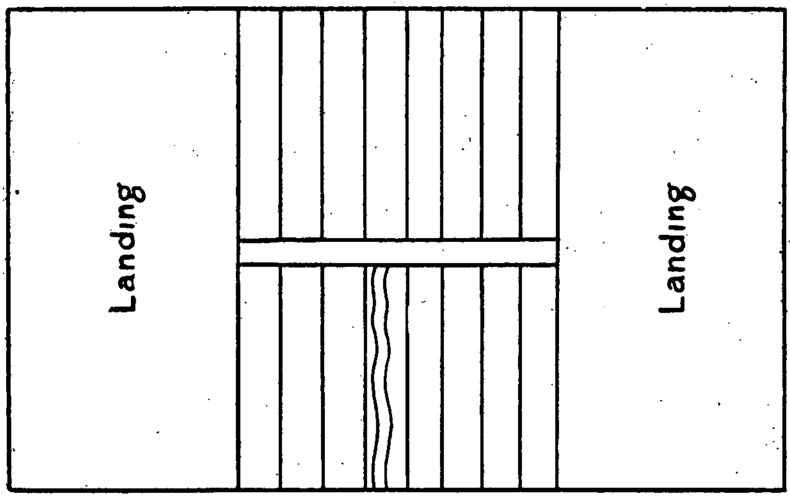


LANDING 7 ft. 6 ins.×3 ft. 6 ins.=26 sq. ft.

16 people on treads
18 people on landings
34 people per storey

FIG. 12

TWO-UNIT STAIRS



LANDING 11 ft.×5 ft. 3 ins.=58 sq. ft.

24 people on treads
38 people on landings
62 people per storey

FIG. 13

THREE-UNIT STAIRS

the time available to evacuate each storey on to the stairs is 2·5 minutes, this reduced rate of evacuation (40 persons per minute) can proceed for 2·5—·4 minutes=2·1 minutes, and 40×2·1 persons will be evacuated.

Hence the total number of persons discharged from each floor on to the stairs in 2½ minutes will be

In the first ·4 minutes	34 persons
In the remaining 2·1 minutes . . .	84 ,,
Total, per floor . . .	118 ,,

In other words, a single 2-unit staircase serving a building with two storeys above the ground storey can evacuate a population of 2×118 persons=236 persons from the two storeys.

Extending this method to three, four and more storeys above ground it will be noted that the number evacuated from each floor in the first ·4 minutes will remain constant at 34, but in the remaining 2·1 minutes, the number will be $\frac{80\times 2{\cdot}1}{\text{No. of storeys}}$.

Thus for 5 storeys above ground storey:

In the first ·4 minutes	34 persons
In the remaining 2·1 minutes $\frac{80\times 2{\cdot}1}{5}=$.	34 ,,
Total, per floor . . .	68 ,,

or, total population in the five storeys above the ground storey=5×68=340 persons.

The principles underlying the foregoing discussion and on which the calculations are based may be expressed in the formula:

Total population P=staircase capacity×no. of storeys above ground storey $+(t_e-t_s)\ r\times w$

where t_e=maximum permissible exit time from any one floor on to the staircase (taken as 2½ minutes).

t_s=time taken for one staircase to be filled to capacity[1] after commencement of evacuation at a rate of flow r.

r=standard rate of flow (taken as 40 persons per unit per minute).

w=width of staircase in units.

For a 2-unit staircase in a building 8 storeys high above the ground storey, this gives—

$$P=34\times 8+(2{\cdot}5-{\cdot}4)\times 40\times 2=272+168=440.$$

The capacity of a 3-unit staircase, *i.e.* 5 ft. 3 in. wide, arranged as shown in Fig. 13 is taken as 62 persons per storey for purposes of calculation.

A detailed study of the assumptions on which these calculations are based would be out of place here, being more suited to a technical paper. The question of simultaneous evacuation is however one of importance and has been a matter of much discussion in all approaches to this problem. Considered broadly it would appear however that any delay in evacuating one or more floors would reduce the immediate burden on the stairs and spread the load over a longer period. In other words, the maximum load will be imposed by simultaneous evacuation.

Variations in the rate of discharge from different floors would normally be expected. The result may lead to variable concentration on the stairs but this does not necessarily reduce the rate of discharge.

[1] The time t_s is more precisely defined as the time taken for a person to traverse a storey height of stairs at the standard rate of flow. For present purposes the above definition is sufficient.

MULTI-STOREY BUILDING WITH NON-UNIFORM DISTRIBUTION OF POPULATION

In order to ascertain the requisite width of staircase it will first be necessary to assume a width and then to determine whether it is adequate.

Consider a building with 5 storeys above the ground storey having a calculated population of 120 persons on the top floor and 60 on each of the remaining floors. Assume a 3 ft. 6 in. staircase.

(i) In the first ·4 minutes 34 persons will have left each floor, leaving 86 on the top floor and 26 on each lower floor.

(ii) The discharge rate from each floor will subsequently be $\frac{80}{5}=16$ persons per minute.

(iii) The remaining 26 people on each of the lower floors will take $\frac{26}{16}=1{\cdot}6$ minutes to leave, and these lower floors with 60 persons on each will therefore be clear in $1{\cdot}6+{\cdot}4=2{\cdot}0$ minutes.

(iv) During these 2·0 minutes the same number will have left the top floor leaving 120−60 persons=60 persons.

(v) The flow from the top floor can now proceed again at the maximum rate and the remaining 60 persons will take 60/80 minutes=¾ minute to leave, thus making the total time 2·75 minutes, slightly greater than the proposed time of 2·5. However as a 25 per cent. allowance is adopted for the second staircase a corresponding proportionate allowance can be made in the evacuation time for purpose of calculation so that the evacuation time of 2·5 minutes may be increased to 3·1. As the calculated time in the example is less than this the two 3 ft. 6 in. staircases would be adequate and in an emergency the single staircase could evacuate the top floor in 2·75 minutes.

ANALYSIS OF THREE-STAIRCASE BUILDING

Consider the building having a typical floor plan as shown below. Assume it has six floors above ground floor, and staircases are arranged as indicated at "X" "Y" and "Z."

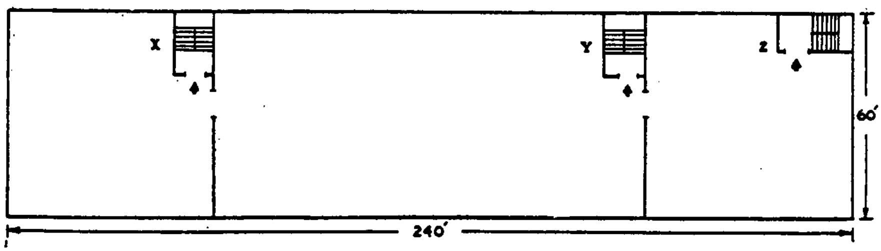


FIG. 14

PLAN OF THREE-STAIRCASE BUILDING

Population per floor at 100 sq. ft. per person = 144
Total population = 6 × 144 = 864.

The analysis is made as follows:

(i) *Assume staircase* X *is not available owing to fire.*

Approximately two-thirds of the population might be expected then to use staircase Y and one-third staircase Z, that is to say:

On Y there would be $\frac{2}{3}\times 864=576$ persons.
On Z there would be $\frac{1}{3}\times 864=288$ persons.

From Table 9 for six storeys a 5 ft. 0 in. stair would be needed for stair Y and 3 ft. 6 in. stair for stair Z.

(ii) *Assume staircase* Y *is not available.*

Approximately two-thirds of the population might use X and again one-third would use Z, giving a 5 ft. 0 in. stairs for X and a 3 ft. 6 in. stairs for Z.

(iii) *Assume staircase Z is not available.*

The population might be expected to be distributed approximately equally between X and Z, *i.e.* 432 on each. As this is less than the number previously considered the 5 ft. 0 in. stairs would be adequate.

The staircase widths would therefore be as follows:

Staircases X and Y each 5 ft. 0 in.
,, Z 3 ft. 6 in.

Without analysis the width of each staircase would from Table 12 be 3 ft. 6 in. This difference is due in part to the fact that the analysis makes no allowance for the staircase assumed to be out of action. As it has been recommended that an allowance of from 25 per cent. to 75 per cent. should be made for any one staircase in the event of fire, the calculation should now be modified as follows:

(a) The width of staircase X, from the previous calculation, is 5 ft. 0 in., and the maximum population it would cater for is, from Table 9, 580 persons.

Assume that this staircase is available for only 25 per cent. of its maximum capacity, *i.e.* for $580/4=145$ persons. The remaining population will be distributed over the other two staircases in the same proportion as before, *i.e.* two-thirds on Y and one-third on Z.

Therefore, on Y there would be $\frac{2}{3}(864-145)=476$ persons,
on Z there would be $\frac{1}{3}(864-145)=239$ persons,
and from Table 9, Y should be 4 ft. 6 in. and Z should be 3 ft. 6 in. wide.

At this stage the revised widths are:
X=5 ft. 0 in., Y=4 ft. 6 in., Z=3 ft. 6 in.

(b) Calculation (a) above has resulted in a reduction in width of staircase Y and it is necessary, therefore, to examine the revised widths on the assumption that this staircase is available to the extent of only 25 per cent. of its maximum capacity.

The revised width of staircase Y is 4 ft. 6 in. and, from Table 9, its maximum discharge value is 510 persons. 25 per cent. of this figure is 128 persons and the remaining $846-128=736$ persons would use the other two staircases in the same proportion as before, *i.e.* two-thirds on X and one-third on Z.

Therefore on X there would be $\frac{2}{3}\times 736=491$ persons,
on Z there would be $\frac{1}{3}\times 736=245$ persons,
and from Table 9, X should be 4 ft. 6 in. and Z should be 3 ft. 6 in. wide.

At this stage the revised widths are:

X=4 ft. 6 in., Y=4 ft. 6 in., Z=3 ft. 6 in.

(c) Calculation (b) above has resulted in a reduction in width of staircase X and, again, the revised widths must be examined on the assumption that this staircase is available to the extent of only 25 per cent. of its maximum capacity.

The revised width of staircase X is 4 ft. 6 in. and the calculation will therefore be indentical with (b). The result will be:

X=4 ft. 6 in., Y=4 ft. 6 in., Z=3 ft. 6 in.

It will be seen that there is no further reduction in the width of any of the staircases and the last set of figures will therefore represent the minimum width of the staircases, allowing 25 per cent. of the maximum discharge value on any one of the staircases.

APPENDIX III

FIRE STATISTICS

In Part I of our Report we drew attention to the lack of statistics relating to causes and numbers of outbreaks of fires. In the course of our later studies we required to know the number of outbreaks due to chimneys and hearths and also to refer to the significance of the structure as being the source of fire as compared with the contents. The Joint Fire Research Organization of the Department of Scientific and Industrial Research and Fire Offices' Committee submitted to us a series of tables based on information collected by the National Fire Service under arrangements which have been made between the Organization and Home Office. We felt that these tables were of such value that we have arranged for them to be incorporated in our Report. We would express our indebtedness to the Joint Fire Research Organization and Home Office for permission to issue the information and are glad to learn that with the transfer of the Fire Services to Local Authorities, the collection of the necessary data is to continue.

Four tables have been prepared from the results of analysis of a random one-in-four sample of reports of occurrences attended by the National Fire Service in Great Britain during 1946.

Table 14—The relation between the occupancy of the building in which the fire started and the supposed cause is shown and the frequencies of fires in which the structure of the building was ignited first are given for each of the groups of occupancies and causes.

Tables 15 and 16—The information in Table 14 is considered in greater detail.

Table 17—Those causes to which had been attributed at least 2·5 per cent. of the total fires in which the building structure was ignited first are analysed still further and the source of ignition is examined in relation to the nature of the structural material.

From Table 14, it will be seen that in approximately 15 per cent. of the fires the structure of the building was ignited first. Special attention is drawn to the ignition of timber under the hearth by the ordinary fire in the grate (Table 17); 516 out of the total of 611 of these fires occurred in houses or flats.

TABLE 14. Supposed cause of fires in buildings * in relation to occupancy in which fire started. One-in-four sample of National Fire Service reports from Great Britain, 1946.

* All types and sizes of buildings are considered, from the small wooden hut in the back garden to the multi-storey framed structure.

OCCUPANCY IN WHICH FIRE STARTED	SUPPOSED CAUSE OF FIRE: Chimney on fire: Confined to chimney	Chimney on fire: Not confined to chimney	Electrical apparatus and equipment	Fire in grate	Gas appliances	Matches and smoking materials	Oil burning appliances	Slow combustion stove	Other sources of ignition	Unknown source of ignition	Total fires	Fires in which building structure was ignited first
Industrial premises	24	7	131	62	77	311	107	111	540	209	1,579	249
Gas, water, electricity, and sewage undertakings	—	—	12	2	5	3	—	4	14	5	45	9
Transport and communications	7	1	86	8	1	71	44	23	72	43	356	47
Commercial premises	55	1	196	33	47	178	17	25	125	74	751	89
Offices, Government and other	12	—	33	18	5	38	4	4	9	10	133	25
Navy, Army, Air Force, and Fire Service Establishments	18	4	27	12	8	39	14	21	41	37	221	54
Professional establishments, public institutions	45	2	41	25	25	44	10	24	72	35	323	80
Places of public entertainment	2	—	20	2	4	53	2	5	17	20	125	24
Private residential houses and flats	4,047	316	605	1,243	197	406	135	49	547	167	7,712	1,096
Clubs, hotels, restaurants, public houses	76	23	69	49	46	91	10	18	175	26	583	117
Other buildings	5	6	33	20	3	559	34	42	210	107	1,019	165
Total fires in buildings	4,291	360	1,253	1,474	418	1,793	377	326	1,822	733	12,847	
Fires in which building structure was ignited first	—	179	125	753	51	90	123	132	490	12		1,955

TABLE 15. Supposed cause of fires in buildings * in relation to occupancy in which

* All types and sizes of buildings are considered from the small

Row No.	Column No. / SUPPOSED CAUSE OF FIRE \ OCCUPANCY OF BUILDING IN WHICH FIRE STARTED	1 Agriculture	2 Mining, quarrying and treatment of non-metalliferous mine and quarry products (excluding gas works)	3 Manufacture of bricks, pottery, glass, etc.	4 Manufacture of chemicals, explosives, paints, oils	5 Manufacture of metals, machines, implements, conveyances	6 Manufacture of textiles and textile goods (not dress)	7 Manufacture of clothing (not knitted) including footwear, and goods of leather and leather substitute; preparation of skins and leather	8 Manufacture of food, drink, tobacco	9 Woodworking, manufacture of cane and basket ware, furniture, fittings	10 Paper making; manufacture of stationery and stationery requisites; printing and book-binding
1	Ashes, hot	4	–	1	1	3	–	3	4	2	–
2	Bombs, flares, fireworks, explosives, etc.	2	–	–	–	–	1	–	2	–	–
3	Candle	2	–	–	–	1	–	1	–	1	1
4	Chimney on fire, confined to chimney	1	–	–	1	2	2	2	4	1	1
5	not confined to chimney	–	–	–	–	2	–	1	1	1	–
6	Chimney, sparks from (outside building)	5	–	–	1	3	1	3	2	2	–
7	Doubtful	1	–	–	–	1	–	–	–	–	–
8	Electric cooker, kettle, refrigerator	–	–	–	–	2	–	–	1	–	–
9	fire, heater, radiator	–	1	–	–	7	1	2	2	–	2
10	iron	–	–	–	–	–	–	4	–	–	–
11	Electric motor	–	–	–	–	7	1	2	3	7	–
12	wire and cable	3	1	–	2	19	4	3	3	6	2
13	other apparatus	2	–	–	2	9	1	2	2	1	1
14	Fire in grate	9	2	–	–	7	4	5	4	3	2
15	Fish frying range (all fuels)	–	–	–	–	1	–	–	–	–	–
16	Flue	6	2	1	1	7	–	3	4	1	2
17	Gas (coal) cooker	–	–	–	–	1	–	–	–	–	–
18	ring	–	1	–	1	2	1	1	3	1	1
19	other apparatus	1	–	1	8	20	3	3	8	1	–
20	Incendiarism	2	–	–	–	1	3	–	–	–	–
21	Intentional burning of grassland, gorse, etc.	2	–	–	–	–	1	–	–	–	–
22	Lightning	–	1	–	–	–	–	–	–	–	–
23	Locomotive, sparks from	2	–	1	3	3	–	1	–	1	–
24	Matches	4	–	–	–	5	–	1	1	–	–
25	Matches, children playing with	25	2	–	–	4	3	–	2	3	–
26	Mechanical heat or sparks	–	1	–	5	20	31	2		11	–
27	Metal, hot	–	1	1	–	22	–	–		–	–
28	Oil engine (including petrol)	17	2	1	–	–	–	–		2	1
29	lamp, stove	49	–	–	–	1	1	–		–	–
30	other apparatus	4	–	–	–	4	–	1		–	2
31	Oxyacetylene cutting and welding apparatus	1	1	1	3	13	–	–	–	–	1
32	Rubbish, burning	19	–	–	–	6	2	1	1	4	1
33	Slow combustion stove	27	2	3	1	16	3	2	8	19	3
34	Smoking materials	42	2	3	4	49	11	11	11	26	9
35	Spontaneous combustion	11	–	–	1	3	4	2	–	1	1
36	Sun's rays	2	–	–	–	–	–	–	–	–	–
37	Taper, lighted paper or sticks	–	–	–	–	1	–	1	–	–	1
38	Do. children playing with	–	–	–	–	1	–	–	–	–	–
39	Miscellaneous	39	3	10	11	29	7	2	25	9	–
40	Unknown source of ignition	48	1	3	12	31	9	9	11	26	7
41	Total fires in buildings	330	23	26	57	303	94	68	105	129	38
42	Fires in which building structure was ignited first	55	6	11	5	43	4	16	17	20	5
	Column No.	1	2	3	4	5	6	7	8	9	10

APPENDIX III

fire started. One-in-four sample of N.F.S. reports from England and Wales, 1946.

wooden hut in the back garden to the multi-storey framed structure.

11 Building, decorating, contracting; slate and stone cutting and dressing	12 Other manufacturing industries, including rubber and synthetic rubber	13 Gas, water, electricity, sewage	14 Transport and communication	15 Commerce; retail shops, including departmental stores	16 Commerce; wholesale dealers and warehouses	17 Offices, Government and other	18 Navy, Army, Air Force establishments	19 Fire Service establishments	20 Professional establishments (other than offices), public institutions	21 Places of public entertainment	22 Private residential houses	23 Private residential flats	24 Clubs, hotels, restaurants, public houses	25 Private huts, unoccupied houses, personal service	26 Miscellaneous and undefined	27 Total fires	28 Fires in which building structure was ignited first	Row No.
3	1	-	4	6	1	2	1	-	8	2	54	4	5	25	4	138	54	1
-	1	1	-	-	-	-	2	-	-	-	5	-	2	2	-	18	4	2
1	-	-	4	5	1	-	-	-	-	-	85	2	-	5	3	112	4	3
-	3	-	6	38	4	7	16	1	39	1	3130	115	76	5	-	3455	-	4
-	-	-	1	1	-	-	3	-	1	-	173	5	10	2	-	201	120	5
3	-	-	1	2	2	1	1	-	2	-	68	3	6	6	4	116	71	6
-	1	-	-	3	-	-	1	-	4	1	3	-	3	1	-	19	-	7
-	-	-	-	55	3	3	-	-	2	2	79	7	12	-	2	168	3	8
-	3	1	8	16	2	9	3	-	7	-	122	17	6	3	2	214	12	9
-	-	-	-	6	1	-	1	-	1	-	43	7	4	1	-	68	10	10
-	2	3	4	32	1	1	2	1	1	-	4	4	7	1	1	84	2	11
4	3	5	50	39	8	15	10	1	21	7	193	13	29	14	3	458	75	12
1	2	2	13	5	2	2	5	-	2	11	47	6	7	2	2	129	9	13
11	3	2	5	26	3	15	10	1	22	2	912	99	44	9	7	1207	595	14
-	-	-	-	2	-	-	1	-	3	-	1	-	100	-	-	108	4	15
-	1	-	2	4	1	-	12	-	16	1	47	4	17	8	1	141	94	16
-	-	-	-	6	2	1	3	-	4	2	68	3	17	-	-	107	6	17
2	-	-	-	13	1	3	1	1	3	-	31	1	5	1	-	73	5	18
2	7	3	-	13	2	1	-	1	18	2	62	6	17	1	-	180	31	19
-	-	-	-	2	-	-	2	-	1	-	6	-	1	2	-	20	-	20
-	-	-	2	1	-	-	-	-	-	-	1	-	-	-	-	7	4	21
-	-	-	-	1	-	-	-	-	2	-	8	-	-	-	-	12	4	22
1	-	-	11	-	2	-	1	-	1	-	4	-	-	-	4	35	20	23
2	1	-	7	10	1	1	2	-	4	1	37	4	3	4	3	91	4	24
12	3	1	18	18	17	5	4	1	14	10	57	6	5	83	329	622	27	25
-	3	2	2	-	3	-	1	-	1	-	-	-	2	1	-	89	6	26
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	25	1	27
3	-	-	15	1	2	-	-	1	1	-	1	-	-	-	-	47	6	28
1	-	-	14	6	-	2	5	-	3	1	62	1	4	24	1	176	43	29
3	-	-	6	4	1	2	2	-	6	-	56	1	6	7	-	107	60	30
3	-	1	13	-	-	-	3	-	-	-	-	-	1	-	1	42	2	31
4	2	-	6	15	4	-	3	2	3	2	9	-	2	20	13	119	57	32
16	5	4	17	14	8	3	18	2	22	5	43	2	16	21	17	292	119	33
22	11	2	38	89	21	31	26	3	21	39	220	27	65	54	62	899	51	34
3	1	4	4	3	2	-	1	-	4	1	6	-	2	2	2	58	1	35
-	1	-	-	3	-	-	-	-	1	-	5	-	-	3	-	15	-	36
-	-	-	-	2	-	1	-	-	1	-	19	-	1	2	8	32	2	37
-	-	-	-	1	-	1	-	-	3	-	22	3	1	1	1	34	2	38
12	5	4	8	19	7	2	9	-	12	7	98	10	13	19	38	398	84	39
14	8	5	37	45	17	10	32	1	32	16	135	10	24	53	41	637	9	40
123	67	40	296	506	119	118	181	16	286	113	5916	360	513	382	544	10,753		41
27	7	7	36	58	16	20	43	2	70	24	780	84	100	83	62		1601	42
11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	

TABLE 16. Supposed cause of fires in buildings * in relation to occupancy in which

* All types and sizes of buildings are considered, from the small

Row No.	Column No.	1	2	3	4	5	6	7	8	9	10
	SUPPOSED CAUSE OF FIRE / OCCUPANCY OF BUILDING IN WHICH FIRE STARTED	Agriculture	Mining, quarrying and treatment of non-metalliferous mine and quarry products (excluding gas works)	Manufacture of bricks, pottery, glass, etc.	Manufacture of chemicals, explosives, paints, oils	Manufacture of metals, machines, implements, conveyances	Manufacture of textiles and textile goods (not dress)	Manufacture of clothing (not knitted) including footwear, and goods of leather and leather substitute; preparation of skins and leather	Manufacture of food, drink, tobacco	Woodworking, manufacture of cane and basket ware, furniture, fittings	Paper making; manufacture of stationery and stationery requisites; printing and book-binding
1	Ashes, hot	–	–	–	–	–	–	1	1	–	–
2	Bombs, flares, fireworks, explosives, etc.	–	–	–	–	–	–	–	–	–	–
3	Candle	1	–	–	–	–	–	–	–	–	–
4	Chimney on fire, confined to chimney	–	–	–	–	–	–	3	1	1	1
5	not confined to chimney	–	–	–	–	–	–	1	–	–	–
6	Chimney, sparks from (outside building)	2	–	–	–	1	–	–	–	–	–
7	Doubtful	1	1	–	–	–	–	–	–	–	–
8	Electric cooker, kettle, refrigerator	–	–	–	–	–	–	–	–	–	–
9	fire, heater, radiator	–	–	–	–	–	–	1	–	1	–
10	iron	–	–	–	–	–	–	–	–	–	–
11	Electric motor	–	–	–	–	1	–	–	–	–	–
12	wire and cable	–	–	–	–	1	–	–	–	2	–
13	other apparatus	–	–	–	–	1	–	–	–	–	–
14	Fire in grate	–	–	–	–	3	–	2	1	–	1
15	Fish frying range (all fuels)	–	–	–	–	–	–	–	–	–	–
16	Flue	–	–	–	–	–	–	–	–	1	–
17	Gas (coal) cooker	–	–	–	1	–	–	–	–	–	–
18	ring	–	–	–	–	–	–	1	–	–	–
19	other apparatus	–	–	–	–	2	–	–	1	1	–
20	Incendiarism	–	–	–	–	–	–	–	–	–	–
21	Locomotive, sparks from	–	–	–	–	–	–	–	–	–	–
22	Matches	–	–	–	–	–	–	–	1	–	–
23	Matches, children playing with	8	–	–	–	–	–	–	2	2	1
24	Mechanical heat or sparks	–	–	1	1	3	5	–	–	–	–
25	Metal, hot	–	–	–	–	5	–	–	–	–	–
26	Oil engine (including petrol)	2	–	–	–	–	–	–	1	1	–
27	lamp, stove	5	–	–	–	1	–	–	1	1	–
28	other apparatus	–	–	–	–	–	–	–	–	–	–
29	Oxyacetylene cutting and welding apparatus	–	–	–	–	5	–	–	–	1	–
30	Rubbish, burning	–	–	–	–	2	1	–	–	–	–
31	Slow combustion stove	3	2	–	–	–	1	–	–	3	–
32	Smoking materials	6	–	–	–	10	2	1	2	1	1
33	Spontaneous combustion	–	–	–	–	1	–	–	1	–	1
34	Sun's rays	–	–	–	–	–	–	–	–	–	–
35	Taper, lighted paper or sticks	–	–	–	–	–	–	–	–	–	–
36	Do. children playing with	1	–	–	–	–	–	–	–	–	–
37	Miscellaneous	6	1	–	4	5	1	–	6	2	4
38	Unknown source of ignition	10	1	–	1	6	1	1	3	3	–
39	Total fires in buildings	45	5	1	7	47	11	11	21	20	9
40	Fires in which building structure was ignited first	6	–	–	1	7	1	4	3	4	1
	Column No.	1	2	3	4	5	6	7	8	9	10

fire started. One-in-four sample of N.F.S. reports from Scotland, 1946.

wooden hut in the back garden to the multi-storey framed structure.

11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	
Building, decorating, contracting; slate and stone cutting and dressing	Other manufacturing industries, including rubber and synthetic rubber	Gas, water, electricity, sewage	Transport and communication	Commerce; retail shops, including departmental stores	Commerce; wholesale dealers and warehouses	Offices, Government and other	Navy, Army, Air Force establishments	Fire Service establishments	Professional establishments (other than offices), public institutions	Places of public entertainment	Private residential houses	Private residential flats	Clubs, hotels, restaurants, public houses	Private huts, unoccupied houses, personal service	Miscellaneous and undefined	Total fires	Fires in which building structure was ignited first	Row No.
1	-	-	-	2	1	-	-	-	1	-	11	3	2	2	-	25	9	1
-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	1	-	2
-	-	-	-	-	-	-	-	-	-	-	3	4	-	1	-	9	1	3
-	1	-	1	12	1	5	-	1	6	1	577	225	-	-	-	836	-	4
1	-	-	-	-	-	-	1	-	1	-	69	69	13	3	1	159	59	5
1	-	-	-	1	-	-	-	-	2	-	4	4	1	3	-	19	11	6
1	-	-	2	1	-	1	-	-	-	-	-	-	-	-	-	7	-	7
-	-	-	-	13	-	-	-	-	-	-	4	1	1	-	-	19	1	8
1	1	-	1	2	-	-	1	-	1	-	9	3	1	-	-	22	3	9
-	-	-	-	-	-	-	-	-	-	-	4	1	-	1	-	6	-	10
1	-	-	-	2	-	-	-	-	1	-	1	-	-	-	-	6	-	11
1	-	1	8	7	-	2	2	-	4	-	19	12	1	1	-	61	8	12
-	-	-	2	2	-	1	1	-	1	-	6	3	1	-	-	18	2	13
4	1	-	3	4	-	3	1	-	3	-	125	107	5	2	2	267	158	14
-	-	-	-	-	-	-	-	-	-	-	-	-	8	-	-	8	-	15
1	-	-	1	1	1	-	1	-	2	-	4	-	1	2	-	15	10	16
-	-	-	-	3	-	-	2	-	-	-	9	5	2	-	-	22	4	17
-	-	-	1	5	-	-	-	-	-	-	4	3	1	-	-	15	1	18
1	2	2	-	1	1	-	-	-	-	-	3	2	4	1	-	21	4	19
1	1	-	-	-	-	-	-	-	1	-	-	-	-	-	-	3	-	20
-	-	-	3	-	1	-	-	-	-	-	1	-	-	-	1	6	3	21
-	-	-	1	1	1	-	-	-	-	-	2	-	-	2	1	9	-	22
1	-	-	3	2	-	-	-	-	-	1	7	4	-	3	11	45	1	23
1	-	-	-	1	-	-	-	-	-	-	-	-	2	-	-	14	1	24
-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	6	1	25
-	-	-	8	-	2	-	1	-	-	-	-	-	-	-	-	15	2	26
-	-	-	1	-	-	-	5	-	-	-	2	3	-	2	-	21	8	27
-	-	-	-	1	-	-	-	-	-	1	8	1	-	-	-	11	4	28
1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	7	-	29
2	-	-	-	-	1	-	-	-	-	-	1	-	1	1	1	10	7	30
1	1	-	6	3	-	1	1	-	2	-	3	1	2	2	2	34	13	31
2	2	-	4	12	6	1	3	-	5	2	31	11	18	4	3	127	7	32
-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	1	5	-	33
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	1	-	34
-	-	-	1	-	-	-	-	-	-	-	3	4	1	-	-	9	1	35
-	-	-	-	1	1	-	-	-	-	-	3	3	-	3	-	12	1	36
2	2	2	8	18	3	1	-	-	4	3	23	6	3	9	14	127	31	37
4	-	-	6	8	4	-	4	-	3	4	14	8	2	7	6	96	3	38
28	11	5	60	103	23	15	23	1	37	12	952	484	70	49	44	2094		39
6	-	2	11	9	6	5	9	-	10	-	141	91	17	11	9		354	40
11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	

TABLE 17. Supposed source of ignition in relation to the nature of the structural building material ignited first. One-in-four sample of National Fire Service reports from Great Britain, 1946

Note:—Only those causes to which had been attributed at least 2·5 per cent. of the total fires in which the building structure was ignited first are analysed in this Table.

BUILDING STRUCTURE FIRST IGNITED	SUPPOSED SOURCE OF IGNITION										
	Hot ashes	Chimney on fire	Sparks from chimney (outside building)	Electric wire and cable	Fire in grate	Flue	Oil lamp, stove	Oil, other apparatus	Burning rubbish	Slow combustion stove	Smoking materials
Building material other than wood											
Ceilings, roof linings	1	3	—	1	4	8	2	1	—	2	—
Partitions, linings to walls	—	1	—	—	2	—	1	—	—	1	—
Roofing felt	—	—	1	1	—	3	1	1	2	1	3
Thatch	—	4	14	1	—	1	—	—	3	—	—
Other	—	—	1	—	—	—	—	—	—	—	—
Structural woodwork											
Exterior of buildings *	7	2	56	3	2	4	—	24	31	3	5
Interior of Buildings											
Door, window frame	—	—	—	1	—	1	—	25	1	2	9
Floor	27	22	—	29	37	11	15	3	11	27	31
Partitions, linings to walls	8	10	—	12	14	3	9	4	2	35	2
Roof	1	40	10	12	20	46	1	2	7	25	—
Timber in chimney flue	9	65	—	—	30	5	—	—	—	2	—
Timber under hearth	1	—	—	—	611	—	—	—	—	3	—
Other	9	32	—	23	33	22	22	4	7	31	8
Total fires in which building structure was ignited first	63	179	82	83	753	104	51	64	64	132	58

* Fires in which the exterior of a wooden door, window frame, roof, etc., were ignited first are classified under this heading.

APPENDIX IV

Proposed Minimum Fire Resistance Requirements for Graded Types of Construction, with Examples of Construction conforming to Type

This table appears as Table 5 in Part I of our Report (*Post-War Building Studies No.* 20).

GRADING OF CONSTRUCTION	MINIMUM FIRE RESISTANCE (IN HOURS) OF MAIN ELEMENTS OF STRUCTURE					EXAMPLES OF CONSTRUCTION‡ CONFORMING TO TYPE
	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 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 of 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.

* † ‡ For footnotes, see page 128.

APPENDIX IV—(*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
	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.

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