BS 5588-4:
1978
(Reprinted, incorporating Amendment No. 1)

Fire precautions in the design and construction of buildings —

Part 4: Code of practice for smoke control in protected escape routes using pressurization

UDC 614.841.334:699.815:721.052.2

Code drafting committee BLCP/24 Precautions against fire

Most of the work on this code was undertaken while the reference number of the responsible committee was BLCP/24. The reference number was changed to FSB/14 in December 1977, but the member ship was not altered because of the change in committee reference.

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This British Standard, having been prepared under the direction of the Codes of Practice Committee for Building was published under the authority of the Executive Board on 30 June 1978

The following BSI references relate to the work on this standard:
Committee reference FSM/14
Draft for comment 76/12178 DC

ISBN 0 580 10260 2

Amendments issued since publication

Amd. No.	Date of issue	Comments
5377	September 1986	Indicated by a sideline in the margin

Contents

Foreword

This new code of practice was prepared under the direction of the Fire Standards Committee.

In addition to the existing BS 5588-1.1, BS 5588-2, BS 5588-3 and BS 5588-5, other parts will include new codes for the precautions to be taken in places of assembly, for means of escape for disabled people, for ventilation and air conditioning ducts, for enclosed shopping complexes and the revision of CP 3:Chapter IV-1, which will appear as BS 5588-1.2

This code offers a method for keeping protected escape routes clear of smoke by pressurizing these routes and so creating a pattern of airflow away from them. The objects of this code are to state general principles and to give both planning and technical data concerning pressurization of protected escape routes. Pressurization is one of several methods of smoke control in buildings in the event of fire and it is not suggested that it is the only effective method in all circumstances. It has however certain advantages inasmuch as it offers greater flexibility of layout than other methods and in some cases reduced costs stemming from this flexibility.

Designers will need to offer the system described in this code to the building control authority as an alternative to the natural ventilation that may be required by specific legislation. Protected escape routes may include corridors, lobbies, staircases and other communication spaces connecting to a final exit. Unprotected routes include spaces within rooms or open storeys and corridors where travel distances apply. The travel distances as specified in other codes or regulations should not be modified because smoke control is employed as described in this code.

Once inside a protected route, people in a building should be able to make their way to a final exit and safety in the open air. It is smoke and toxic gases, rather than flame, that will in the first instance inhibit this movement and the exclusion of smoke and gases from the protected routes is thus of great importance.

In normal fire-prevention design the intention always will be to confine the fire within a fire compartment and, although this may be effective in limiting the spread of fire, smoke will readily spread to adjacent spaces through the various leakage openings that occur in the compartment enclosure, such as cracks, openings around pipes, ducts, airflow grilles and doors. In good building practice the leakage at some of these points will be minimized but it is not generally possible to seal them completely.

There are two main factors that determine the movement of smoke arising from a fire in a building. These are:

a) the mobility of smoke that results from its consisting of hot gases less dense than the surrounding air;

b) the normal air movement (which may have nothing to do with the fire) that can carry smoke, sometimes slowly, sometimes quickly, to all parts of the building.

Air movement is itself controlled by:

a) the stack effect (see **3.1.4**);

b) the wind, all buildings having some air leaks and wind action contributing to air movement through the leaks;

c) any mechanical air-handling system installed in the building.

Pressurization provides pressure differences that oppose and overcome those generated by the factors causing movement of smoke. In pressurization, air is injected into the protected escape routes, i.e. into staircases, lobbies or corridors, to raise their pressure slightly above the pressure in adjacent parts of the building. Consequently smoke or toxic gases will be unlikely to find their way into escape routes.

The use of a system to extract air from spaces that are pressurized is very strongly deprecated because it will render the maintenance of the required pressure in the escape routes extremely difficult.

It is necessary to determine not only where the fresh air supply for pressurization is to be introduced into a building but also where that fresh air will leak out and what paths it will take in the process. The aim will be to establish a pressure gradient (and thus an airflow pattern) with the protected escape routes at the highest pressure and the pressure progressively decreasing in areas remote from the escape routes. The design criteria given in detail in clause **5** deal with the various ways in which the escape of pressurized air can be arranged.

A pressurization system for smoke control should:

a) give positive smoke control in the protected escape routes;

b) be readily available when a fire starts;

c) be reliable and capable of functioning for a period corresponding to the standard of fire resistance of the elements of structure in a building;

d) be simple and economic.

Some of the advantages that can be expected from the use of pressurization are:

a) staircases and lobbies need not be placed on external walls;

b) smoke shafts may not be required as a means of alternative ventilation;

c) it may be possible to omit some "smoke stop" doors from escape routes;

d) the additional staircase considered necessary in calculating the number of staircases required in relation to the population density when other methods of smoke control are used may possibly be omitted;

e) conservation of energy.

Diagrams that accompany the text in this code are intended only to clarify points made in the text. It should not be assumed that the arrangements shown are more satisfactory than others that may be devised.

Consultation with the building control authority at an early stage is recommended, to check not only that proposals for means of escape are satisfactory but also that other building regulations, concerned for example with ventilation of parts of the building for public health purposes, are satisfied.

This code does not contain all the necessary information for the satisfactory design of a pressurization scheme, which should be undertaken by a competent person.

A British Standard does not purport to include all the necessary provisions of a contract. Users of British Standards are responsible for their correct application.

Compliance with a British Standard does not of itself confer immunity from legal obligations.

Summary of pages

This document comprises a front cover, an inside front cover, pages i to iv, pages 1 to 38, an inside back cover and a back cover.

This standard has been updated (see copyright date) and may have had amendments incorporated. This will be indicated in the amendment table on the inside front cover.

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1 Scope

This code of practice gives guidance on the use of pressurization in buildings for the purpose of smoke control in protected escape routes.

The code is intended to apply to new buildings, though there is no reason why the principles should not be used when existing buildings are to be altered or adapted. it is intended initially for application to protected escape routes in flats and maisonettes, and in offices and shops.

The principles stated in the code may be used for other occupancies and purpose groups where the fundamental aim is to keep the protected escape route clear of products of combustion.

This code is not intended to apply to shopping malls and town centre redevelopments. Information on these will be found in HMSO publication "Fire Prevention Guide 1: Fire Precautions in Town Centre Redevelopments".

2 References

The titles of the publications referred to in this code are listed on the inside back cover.

3 Definitions

For the purposes of this code, the definitions given in BS 4422, together with the following, apply.

3.1
air duct

a passageway for the transmission of air

3.2
air escape or air venting

the movement of air out of a building through a low-resistance path provided by incidental or specially provided apertures, the air movement being caused by pressure differences developed in the building

3.3
air leakage

the movement of air, generally from a pressurized space through openings that have relatively small cross-sectional area

3.4
air supply

a mechanically driven current of air lead by suitable ductwork or impelled by the direct action of a fan

3.5
buoyancy

an upward force exerted on a fluid when it is surrounded by a denser fluid

3.6
leakage area

the cross-sectional area of the air leakage path, measured normally to the direction of airflow and generally integrated into a total area for a particular building component (such as a door or a window)

3.7
lobby

a space in a building used to separate one part of the building from another part, usually separating a staircase from the general accommodation

3.8
plenum

a compartment or chamber or space to which one or more air ducts are connected and that forms part of an air distribution system

3.9
pressure differential

the difference in pressure between two adjacent spaces in a building

3.10
pressurized space

a space in a building in which the air pressure is maintained at a higher value than that in the rest of the building by direct input of an air supply

3.11
pressurization

a method of protecting escape routes against the ingress of smoke by maintaining the air within them at pressures higher than those in adjacent parts of the building

3.12
pressurization level

the pressure difference between the pressurized space and the accommodation served by the pressurized escape route [expressed in pascals (Pa)][1)]

3.13
simple lobby

a lobby that has no door opening out of it other than a door to a staircase and a door (or doors) leading to the accommodation

NOTE A lobby that has doors to toilets or doors to lifts is not a simple lobby.

3.14
stack effect

the pressure differential caused by the air inside the building being at a temperature different from that of the air outside the building, which, when there are openings top and bottom, will promote natural airflow through the building, upwards when the building air is warmer than the outside air and downwards when it is cooler

4 The building

4.1 General

4.1.1 *General principle of pressurization.* The spaces to be pressurized will be those that constitute the protected escape routes. These are the staircase(s), the lobbies and in some cases the corridors. One or more of these spaces will be pressurized and the general principle is that smoke control will only be satisfactory for those spaces that are pressurized, i.e. that have an input of pressurizing air (air supply). Thus the extent to which smoke encroachment is to be prevented will determine the spaces to be pressurized.

4.1.2 *Single-stage or two-stage pressurization.* The pressurization system can be designed to operate only in an emergency. This is called a single-stage system. Alternatively, a continuously operating low level of pressurization of the appropriate spaces can be incorporated as part of the normal ventilation with provision for an increased level of pressurization to be brought into operation in an emergency. This is called a two-stage system. (See **5.2.1**.)

The two-stage system is generally regarded as preferable because some measure of protection is always operating and therefore any smoke spread in the early stages of fire will be prevented. However, either method will be acceptable subject to any special circumstances dealt with in this code.

4.1.3 *Combustible material in protected escape routes.* It is important that any staircase, lobby or corridor of a protected escape route should contain or be likely to contain, a minimum of combustible material in which a fire could occur.

4.2 Methods of pressurizing the spaces to be pressurized

4.2.1 *Method 1. Pressurizing staircase(s) only.* The protection given by this method is entirely confined to the vertical part of the escape route. It is only appropriate in buildings where no smoke control is needed for the horizontal part of the escape route on each floor of the building and, in general, it should be used only when a staircase is approached directly from the accommodation area or through a simple lobby. By definition (see **3.13**) this lobby should not give access to lifts or other rooms (e.g. toilets) that could constitute an appreciable leakage path and allow the pressurizing air to bypass its required direction of flow.

[1)] 1 Pa = 1 N/m^2.

The simple lobby, which may be required to complete the fire-protecting enclosure of the staircase, will serve to reduce the effect of an open door to the pressurized staircase.

The simple lobby should be unventilated, in which case it will be automatically pressurized by the air flowing out of the staircase. Figure 1 shows examples of pressurized staircases leading into simple lobbies. The resulting pressurization of the lobbies is indicated, as also is the effect of an open lobby door.

During a fire emergency all protected staircases interconnected by lobbies, corridors or accommodation areas should be simultaneously pressurized.

4.2.2 *Method 2. Pressurizing the staircase(s) and all or part of the horizontal route*

4.2.2.1 *General.* In every building in which each floor has a horizontal component of the protected escape route (other than the simple lobby mentioned in **4.2.1**) the pressurization should be carried into the lobby and possibly into the corridor beyond.

This arrangement carries the protection right up to the door leading into the accommodation area in which a fire might occur. Additionally, the effect of an open door on the pressurization levels is largely localized on the floor concerned.

During a fire emergency all protected staircases and associated lobbies/corridors forming part of the whole pressurization scheme should be simultaneously pressurized.

4.2.2.2 *Pressurizing staircase and lobby.* If a lobby separating the staircase from the accommodation is other than a simple lobby, this lobby should be pressurized independently of the staircase, i.e. it should have pressurizing air supplied from a duct (or source) that is separate from that supplying the staircase. The lobby pressure should be equal to or slightly below the pressure in the staircase (but not more than 5 Pa below). Figure 3 shows an example of independently pressurizing staircase and lift lobby and indicates the effect of an open door.

4.2.2.3 *Pressurizing staircase, lobby and corridor.* If the lobby opens into a corridor of substantial construction (i.e. 30 min fire resistance or more) that forms part of the protected escape route, the pressurization may with advantage be extended to include the corridor and so take the smoke control right up to the door of the accommodation unit, office or flat. To do this an independent air supply should be provided to the corridor and the pressure should be equal to or slightly below that in the associated lobby, but not more than 5 Pa below.

There are difficulties associated with this extension of the pressurization. If the corridor has many doors (or other leakage paths) the air supply needed will be large, each door should be self-closing and each unpressurized space opening onto the corridor should have adequate leakage to the outside air (as recommended in **5.5**).

4.2.3 *Method 3. Pressurizing lobbies and/or corridors only.* In some buildings it may be found necessary, perhaps for constructional reasons (such as difficulty in arranging the required ductwork for independent pressurization) to allow the staircase to be pressurized by the air that leaks into it from the associated pressurized lobbies or corridors. If properly designed this can be a satisfactory method but in some cases it may be found that the total air supply needed for pressurizing the lobbies only may be greater than that needed if the staircase and lobbies are independently pressurized.

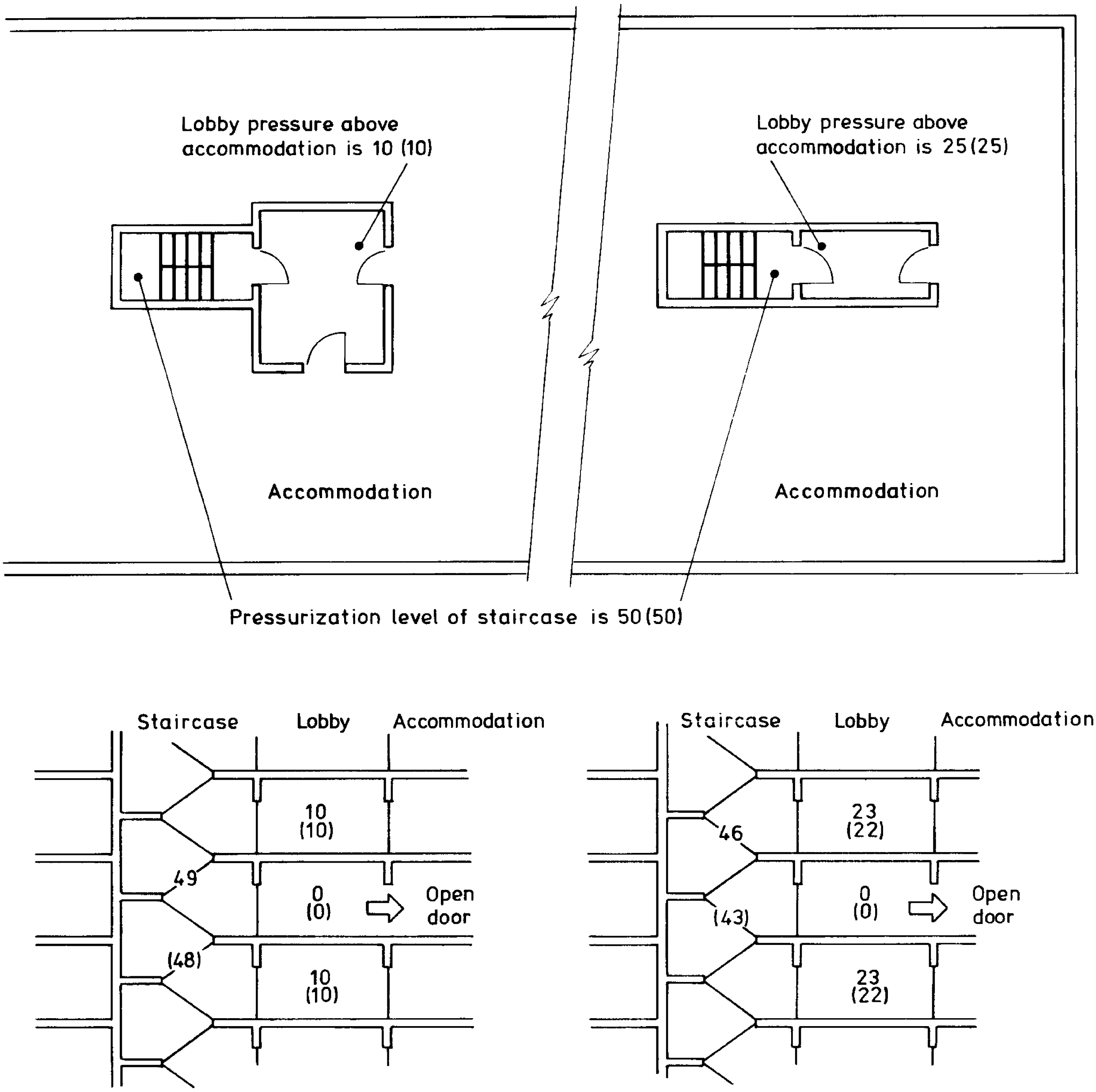
In this method the staircase should not be permanently ventilated except by any opening shown to be necessary by the calculation for the open-door condition dealt with in **5.3.2.8**.

All pressurized lobbies and/or pressurized corridors on all floors in a building should be pressurized in an emergency.

4.2.4 *"Pressurizing" the whole building (not recommended).* Designs have been suggested for a scheme in which pressure differentials are not developed inside the building but air is introduced in such a way that the whole building is raised to a pressure in excess of that obtaining outside the building. In the event of fire, airflows are set up in opposition to the smoke flow by opening vents on the fire floor. This system has been suggested for buildings in which the internal divisions are so leaky that pressurizing particular spaces (such as staircases or lobbies) is not possible.

In the UK there is no experience with this method and it is suggested that, unless there are over-riding reasons for its adoption in a special case, it does not constitute a satisfactory method.

To design this type of system the details, including location, of the air leakage from the external wall are required. If this leakage is appreciable (as suggested by some of the information available), a wastefully high amount of pressurizing air is required.

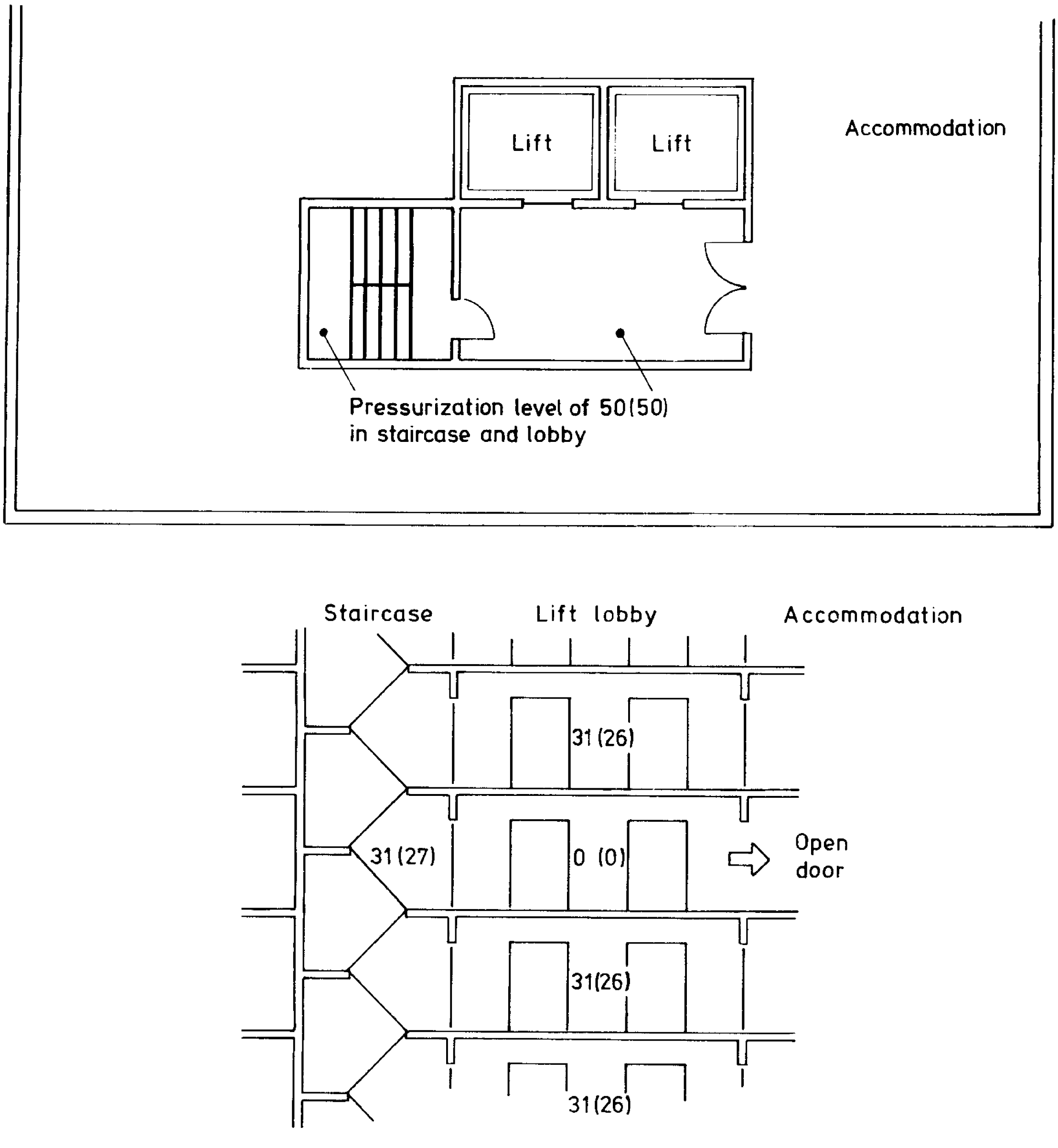


The two upper diagrams show pressurization levels and pressures with the lobby/accommodation doors shut. The two lower diagrams show pressurization levels and pressures when one lobby/accommodation door is open, the others remaining shut.

For a 10-storey building, pressurization levels and pressures in Pa shown thus: 49
For a 5-storey building, pressurization levels and pressures in Pa shown thus: (48)

Figure 1 — Pressurizing staircase only

Figure 2 — *Deleted*



The upper diagram shows pressurization levels with the lift lobby/accommodation doors shut. The lower diagram shows pressurization levels with one lift lobby/accommodation door open, the other doors remaining shut.

For a 10-storey building, pressurization levels and pressures in Pa shown thus: 31
For a 5-storey building, pressurization levels and pressures in Pa shown thus: (26)

Figure 3 — Pressurizing staircase and lift lobby

The effectiveness of a system pressurizing the whole building relies entirely on the opening of venting on the fire floor only. Venting elsewhere can cause smoke to spread to other parts of the building. In particular, an open door at the foot of a staircase can cause that staircase to become filled with smoke. Consequently, if this system is used additional "smoke stop" doors have to be installed. For these reasons the pressurization of the whole building is not recommended in this code of practice.

4.3 Interaction between several pressurized spaces

4.3.1 *General.* In a building, particularly a large building, there may be several pressurized spaces. These may be directly interconnected or they may be separated by a large unpressurized area. The presence of several pressurized spaces in a building does not generally create a problem.

4.3.2 *Directly connected pressurized spaces.* This condition will arise when the staircase and the lobby (and perhaps the corridors) are pressurized. This will apply to many buildings. In such a system the design aim should be to ensure airflow from the staircase, through the lobby, through the corridor (if appropriate) and into the accommodation space where a fire might occur.

There is no objection to all the connected pressurized spaces being maintained at the same pressure, which should be that given in Table 1 for the appropriate building height.

If there is a difference in pressure between adjacent pressurized spaces, this should be small and should not exceed 5 Pa. The pressurized space nearest to the accommodation should always be at the lower pressure.

This design condition will be disturbed if, for instance, a door on the staircase is opened on to an unpressurized space. This circumstance may be regarded as a shortlived temporary occurrence during which the staircase pressure will fall below that of the adjacent lobby, but the lobby pressurization will still maintain a sufficient airflow towards the possible fire area. A design check is outlined in clause **5** to ensure that this condition is satisfied.

4.3.3 *Pressurized spaces that have no direct connection.*This condition arises when a building has two or more pressurized escape-route systems opening out into the same unpressurized accommodation area.

There are no particular problems or restrictions associated with this arrangement because each escape-route system should have its own independent pressurizing plant and the unpressurized accommodation space should have adequate leakage arrangements to allow the pressurizing air from all the pressurized areas to escape to open air. Provided these conditions are satisfied there will be no possibility of any interaction between the several pressurized parts of the building.

4.4 Single-staircase or multiple-staircase buildings

4.4.1 *The staircases.* The factors associated with floor area that determine whether a building may have a single staircase or needs to have two or more staircases will not be affected by the proposal to use pressurization in the building, except that a pressurized staircase (with a lobby and/or corridor, as appropriate) may be considered safer than an escape route that is naturally ventilated.

4.4.2 ***Restrictions***

4.4.2.1 *Pressurized and unpressurized staircases in the same building.* No restrictions will arise when all the staircases in a building are pressurized, but the use of pressurized and naturally ventilated staircases in the same building will introduce difficulties and should be avoided if possible. It should be considered only if the staircase is cross ventilated and separated from the pressurized staircase(s) by a large unpressurized undivided space from which the air can escape at points well away from the unpressurized staircase(s), in order to prevent the unpressurized staircase from becoming filled with smoke.

Under no circumstances should a pressurized staircase be connected by a corridor or lobby to an unpressurized staircase.

4.4.2.2 *Pressurized and unpressurized spaces in the same escape route.* Another possibility is a mixed system for the escape route, for instance a pressurized staircase with a naturally ventilated lobby between it and the accommodation. In this example the protection afforded by the pressurization will be completely confined to the staircase. The pressurization will do nothing to keep the naturally ventilated lobby clear of smoke; it will only provide a steady supply of fresh air to dilute any smoke entering the lobby. This arrangement is not recommended and the lobby in this position should be unventilated.

4.5 Relation between emergency pressurization and the normal air conditioning system. It has been explained that the purpose of a pressurization system is to establish an airflow condition in the building that will prevent the smoke from a fire moving towards or past the escape route doors. This is achieved by maintaining the escape routes at an excess pressure by providing them with a mechanically driven constant supply of fresh air, and, additionally, by providing for this air to leak out of the building at identified places in or near external walls that are as far as possible from the escape route doors.

It is therefore preferable that the airflow pattern established in the building by the normal air conditioning system should also be away from the escape route entrance, with the vitiated air being removed for exhaust or recirculation at points remote from the escape route entrances.

If the pressurization system is two-stage, i.e. has a constant running feature that maintains the escape routes always at a slight excess pressure, the general air conditioning system to fit in with this arrangement will probably adopt a satisfactory airflow pattern that is always away from the escape routes.

When the pressurization system is single-stage, i.e. operates in an emergency only, the interaction between it and the normal air conditioning arrangement may not be so obvious but nevertheless it should be considered in the overall design concept.

An air conditioning system that uses the corridors or the false ceiling of a corridor as the exhaust plenum for the vitiated air should not be used in conjunction with a pressurization system unless special arrangements are made for closing off the whole exhaust system in case of fire.

In any case, an air conditioning system that could encourage smoke to enter the corridors is not favoured for fire safety reasons even if there is no pressurization in the building.

4.6 Integration of emergency system with normal air conditioning equipment. It is suggested that the normal air conditioning system and the pressurization system should be treated as an integral whole when design calculations are carried out. This will certainly be necessary when the pressurization is two-stage, i.e. a reduced level of pressurization will be operative at all normal times and so the air volumes and air movement used for it need to be considered in the wider context of the air movements in the normal ventilation system.

When the emergency pressurization is brought into action the following changes in the normal air conditioning system should be made.

a) Any recirculation of air should be stopped and all exhaust air vented to atmosphere, e.g. by means of a suitable damper.

b) Any air supply to the accommodation spaces should be stopped.

c) The exhaust system may be continued, provided:

1) the positions of the extraction grilles are compatible with the need to establish a general airflow that is not towards the protected escape route entry;

2) the construction of the ductwork and fans is such that it will not be rendered inoperable by hot gases and smoke;

3) there is no danger of smoke spreading to other floors by the path of the extraction system; to ensure this the extraction fan has to be kept running and therefore its position and electrical supply have to be protected.

The signal to initiate all these changes in the operation of the air conditioning system should come from the same source as that which operates the emergency pressurization.

The use of a smoke detector in the air conditioning ductwork should not be relied on for this purpose because of the dilution of the smoke that will occur when several floors are served by the same system. This could cause a delay in operating the necessary adjustment to the air conditioning system in case of fire.

5 The system

5.1 Basic design criteria for designing the system and its component parts

5.1.1 *Basic design.* The criterion is to establish in the building a pressure gradient pattern that will always ensure that smoke moves away from the escape route. To do this the escape route is maintained at an excess pressure and adequate air leakage has to be provided from the accommodation areas.

5.1.2 *Pressure differentials.* These are established by maintaining a continuous supply of fresh air, fed by mechanical means into the pressurized space.

5.1.3 *Space being pressurized.* This will unavoidably, in any building, have air leakage paths in its enclosing surfaces. These leakage paths will be the cracks round doors, cracks round windows, direct leakage through the building fabric, leakage through air conditioning ductwork, and so on. If a pressure difference is maintained between a pressurized space and its adjacent space(s) air will flow through these leakage paths.

5.1.4 *Pressurization system.*This is designed by first identifying the leakage paths (see **5.1.3**), estimating their size and then calculating the airflow that will be needed to create and maintain the required pressure difference across these leakage paths. A constant air supply of this magnitude has then to be delivered to the space it is desired to pressurize.

5.1.5 *General principle.*The important principle to understand is that to maintain a space A at a higher pressure than space B, the spaces being connected by, say, a closed but leaky door, there must be a leakage path from B so that a flow from A to B can be maintained. If there were no leakage path from B, air fed into A would raise both A and B to the same excess pressure above the surroundings and smoke from a fire in B could not be prevented from spreading to A.

5.1.6 *Components of a pressurization system.* These are:

a) a mechanically driven supply of fresh air ducted directly into each pressurized space (i.e. staircase, lobby or corridor);

b) air leakage paths from each pressurized space;

c) an air leakage path from the accommodation areas.

In order to design a pressurization system for a building all of these factors have to be determined or specified. Each will partly depend on the level of pressurization required, which is the first factor to be decided.

5.2 The pressure differentials

5.2.1 *One-stage or two-stage systems.* The relative merits of a one-stage or two-stage system have been discussed in **4.1.2** and the pressure levels relative to each are now specified.

In *a single-stage system* the pressurization is applied only when a fire situation occurs, and in a *two-stage system* a low level of pressurization is maintained at all times and is increased to the emergency level when a fire occurs.

The emergency level of pressurization will be the same whether a one-stage or two-stage system is used and will depend on the height and position of the building. The reduced level of pressurization for the two-stage system will also depend on the height and position of the building.

5.2.2 *Pressurization levels to be used.* The level of pressurization used for design purposes for any pressurized space in a building should not be less than the appropriate level for the building height given in Table 1 (or greater than 60 Pa[2)]) with all doors to the pressurized space or spaces closed, and also all doors to simple lobbies closed.

NOTE 1 Buildings used for the very young or old or for handicapped people may need special consideration to ensure that doors can be used in spite of the force created by the pressure differential.

NOTE 2 The force that can be exerted to open a door will be limited by the friction between the shoes and the floor and it may be necessary to avoid having a slippery floor surfaces near doors opening into pressurized spaces in buildings in which there are very young persons.

NOTE 3 The self-closing mechanisms on doors opening into pressurized spaces should be adjusted to require the minimum force compatible with the effective closing of the door in normal use. In buildings in which young children may be unaccompanied, consideration of the forces needed to open self-closing doors may be necessary. Doors opening out of a pressurized space should have a closer that can keep the door shut against the pressure.

[2)] 1 Pa = 1N/m^2; 25 Pa ≈ 0.1 in water gauge.

Table 1 — Pressurization levels

Building height	Pressurization levels	
	Emergency operation	Reduced operation for stage 1 of a two-stage system
	Pa	Pa
Up to 12 m or below ground	50[a]	8
Above 12 m	50	15

[a] In some circumstances 25 Pa may be appropriate. See Fire Research Note 958 published by HMSO.

The pressurization levels given in Table 1 are those for a staircase. If possible, the same levels should be used for lobbies and corridors but levels slightly lower may be used for these spaces if desired. The difference in pressurization levels between staircase and lobbies (or corridors) should not be greater than 5 Pa.

Unusual building configurations, especially with windy exposures, may need special consideration.

5.3 The air supplies needed to obtain the required pressure differentials

5.3.1 General principles

5.3.1.1 *Calculation of air supplies.* The air supply needed to obtain a given pressure differential is determined by the air leakage out of the space. When air flows through a restriction such as the crack around a door or a window as the result of a pressure differential across the restriction, the relationship between the rate of airflow, the area of the restriction and the pressure differential is given by

$$Q = 0.827 \times A \times (P)^{1/N} \quad ...(1)$$

where

Q is the airflow (m^3/s),

A is the area of the restriction (m^2),

P is the pressure differential (Pa),

N is an index that can vary between 1 and 2.

For wide cracks such as those around doors and large openings, the value of N can be taken to be 2 but for the narrow leakage paths formed by the cracks round windows the more appropriate value of N is 1.6.

The values of $(P)^{1/N}$ for these two values of N over the range of pressures (1 Pa to 50 Pa) likely to be needed for the calculations for the design of a pressurization system are given in Table 2.

Equation (1) is used to derive the air supply needed to obtain a given pressurization level within a space, taking into account the total effective area of the leakage paths out of the space. In most cases the predominant leakage paths will be through doors, so that N can usually be taken as 2; thus

$$Q_E = 0.827 \times A_E \times (P_E)^{1/2} \quad ....(2)$$

where

Q_E is the air supply to the pressurized space (m^3/s),

A_E is the total effective area of the leakage paths out of the space (m^2),

P_E is the pressurization level in the pressurized space (Pa).

5.3.1.2 *Rules for adding leakage areas together.* Leakage paths out of a pressurized space can be either in series as shown in Figure 4, in parallel as shown in Figure 5, or in combinations of series and parallel paths as shown, for example, in Figure 6(a).

Table 2 — Values of $(P)^{1/N}$ for $N = 2$ and $N = 1.6$

P	$(P)^{1/2}$	$(P)^{1/1.6}$	P	$P^{1/2}$	$P^{1/1.6}$
1	1.0	1.0	26	5.1	7.7
2	1.4	1.5	27	5.2	7.8
3	1.7	2.0	28	5.3	8.0
4	2.0	2.4	29	5.4	8.2
5	2.2	2.7	30	5.5	8.4
6	2.4	3.1	31	5.6	8.6
7	2.6	3.4	32	5.7	8.7
8	2.8	3.7	33	5.7	8.9
9	3.0	3.9	34	5.8	9.1
10	3.2	4.2	35	5.9	9.2
11	3.3	4.5	36	6.0	9.4
12	3.5	4.7	37	6.1	9.6
13	3.6	5.0	38	6.2	9.7
14	3.7	5.2	39	6.2	9.9
15	3.9	5.4	40	6.3	10.0
16	4.0	5.6	41	6.4	10.2
17	4.1	5.9	42	6.5	10.3
18	4.2	6.1	43	6.6	10.5
19	4.4	6.3	44	6.6	10.6
20	4.5	6.5	45	6.7	10.8
21	4.6	6.7	46	6.8	10.9
22	4.7	6.9	47	6.9	11.1
23	4.8	7.1	48	6.9	11.2
24	4.9	7.3	49	7.0	11.4
25	5.0	7.5	50	7.1	11.5

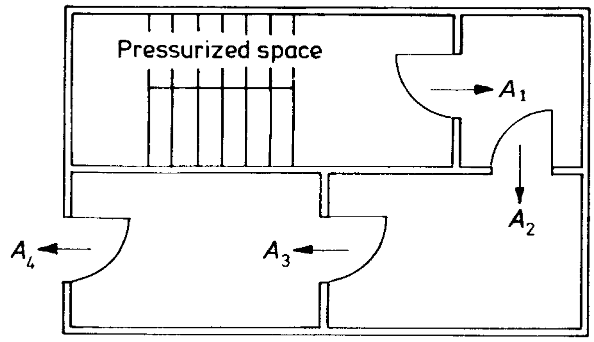
An example of leakage paths in parallel would be all of the doors opening out of a staircase, each door leading to an unpressurized space.

For parallel paths the total leakage area is determined by the simple addition of all the leakage areas concerned. Referring to Figure 5,

$$A_{\text{total}} = A_1 + A_2 + A_3 + A_4 \quad \text{....(3)}$$

It should be noted that this calculation applies strictly only to leakage paths having the same value of N in equation (1). In practice the predominant leakage paths in parallel from the unpressurized space will almost invariably be through doors or other openings large enough for N to be taken as 2.

Leakage paths in series occur when there is an intermediate space into which the air from a pressurized space first passes before finally leaking out to the unpressurized space through another leakage path. Examples of this are the simple approach lobby interposed between the staircase and the other accommodation, or a lift shaft that connects all the pressurized lobbies and into which air flows from each lobby and then flows out to the open air via the vent opening at the top of the lift shaft.



NOTE The doors shown are normally shut and the airflow shown takes place at the cracks around the doors.

Figure 4 — Leakage paths in series

For series paths the total effective leakage area may be determined by using equation (4):

$$\frac{1}{(A_{total})^2} = \frac{1}{(A_1)^2} + \frac{1}{(A_2)^2} + \frac{1}{(A_3)^2} + \frac{1}{(A_4)^2} \quad ....(4)$$

(see Figure 4)

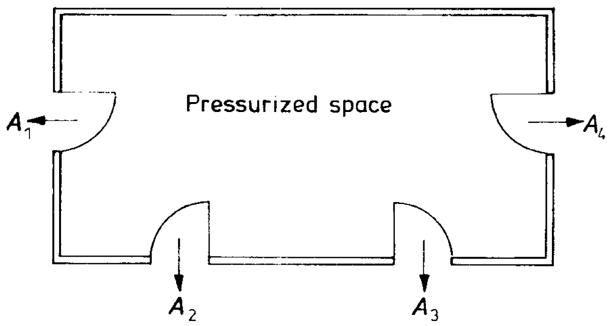
In the context of a pressurization system it is unusual for more than two leakage paths to be in series, so that the calculation becomes

$$\frac{1}{(A_{total})^2} = \frac{1}{(A_1)^2} + \frac{1}{(A_2)^2} \quad ...(5)$$

or

$$A_{total} = \frac{(A_1 \times A_2)}{(A_1^{\ 2} + A_2^{\ 2})^{1/2}} \quad ...(6)$$

The calculations using equations (4), (5) and (6) apply strictly only to leakage paths for which the value of N in equation (1) is 2 (i.e. for doors). However, the method may be used as an approximate calculation when windows form part of a series leakage path.



NOTE The doors shown are normally shut and the airflow shown takes place at the cracks around the doors.

Figure 5 — Leakage paths in parallel

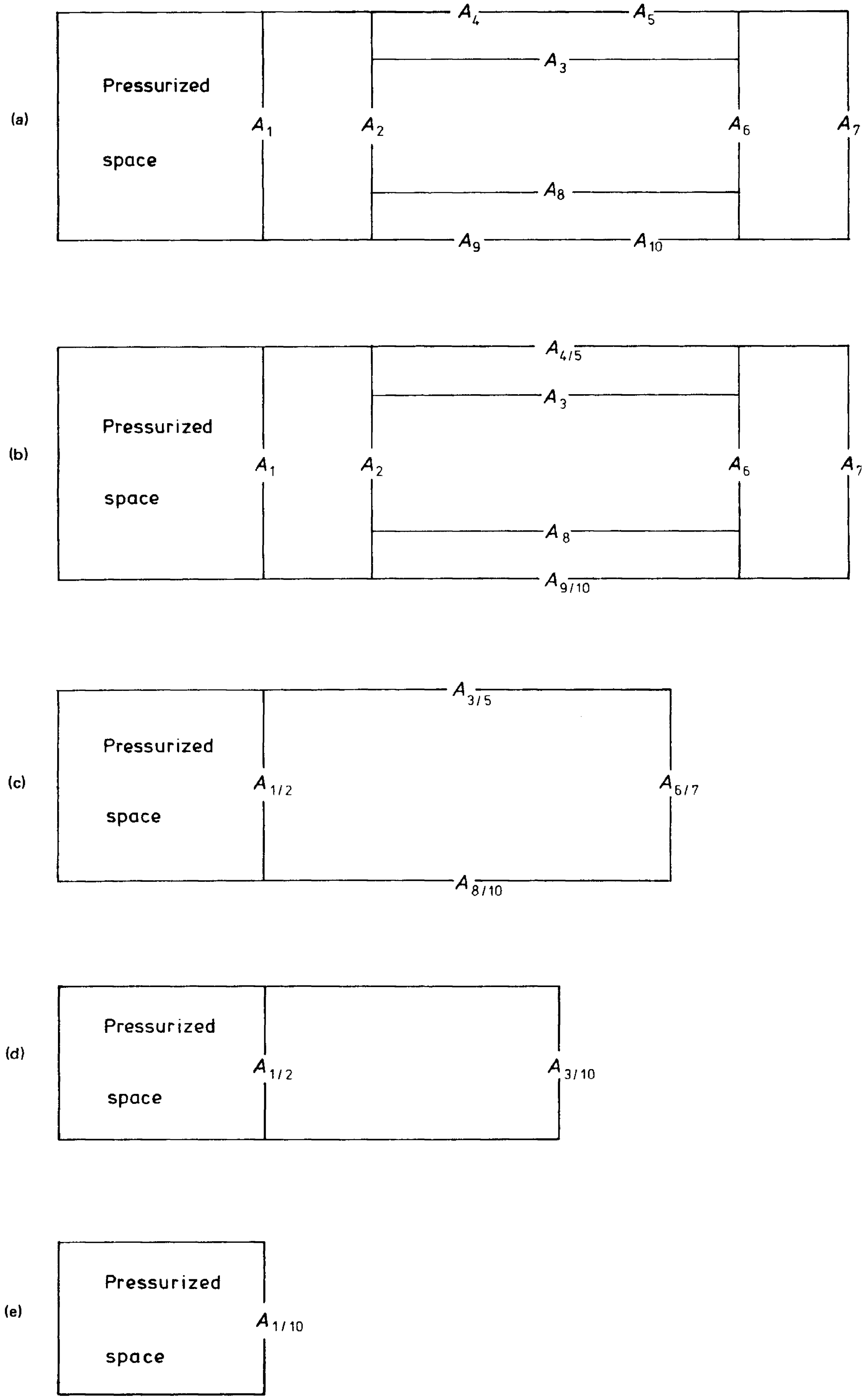


Figure 6 — Steps in obtaining the equivalent resistance of a combination of series and parallel paths of air leakage

For combinations of series and parallel paths. The total effective leakage of combinations of series and parallel paths can usually be obtained by successively combining simple groups of individual leakages into their equivalents, first combining leakages in parallel between the same spaces, and series leakages with only one inlet and one outlet in a space. Figure 6 gives an example of this process. Such calculations apply strictly only to leakage paths for which the value of *N* in equation (1) is 2 (i.e. for doors). However they may be used for an approximate calculation when windows form part of a series leakage path.

Thus, in Figure 6(b),

$$A_{4/5} = A_4 + A_5 \qquad ...(7)$$

$$A_{9/10} = A_9 + A_{10} \qquad ...(8)$$

Then in Figure 6(c),

$$A_{1/2} = \frac{A_1 \times A_2}{(A_1^2 + A_2^2)^{1/2}} \qquad ...(9)$$

$$A_{3/5} = \frac{A_3 \times A_{4/5}}{(A_3^2 + A_{4/5}^2)^{1/2}} \qquad ...(10)$$

and similarly for $A_{6/7}$ and $A_{8/10}$.

In Figure 6(d),

$$A_{3/10} = A_{3/5} + A_{6/7} + A_{8/10} \qquad ...(11)$$

The total equivalent leakage from the pressurized space is given by

$$A_{1/10} = \frac{A_{1/2} \times A_{3/10}}{(A_{1/2}^2 + A_{3/10}^2)^{1/2}} \qquad ...(12)$$

5.3.2 *Leakage areas for various components*

5.3.2.1 *Doors.* The air leakage past a door will, in general, be confined to the cracks around the door. The total value of the leakage area will therefore depend on the length of the cracks (i.e. on the size of the door and on the design and operation of the door). In general, doors enclosing a pressurized space will also need to have fire resistance, and this will ensure that the door is close-fitting in its frame.

Typical leakage areas for the four types of door likely to be found as the closure to a pressurized space are given in Table 3.

Table 3 — Typical leakage areas for four types of door

Type of door	Size	Crack length	Leakage area
		m	m^2
Single-leaf in rebated frame opening into a pressurized space	2 m high 800 mm wide	5.6	0.01
Single-leaf in rebated frame opening outwards from a pressurized space	2 m high 800 mm wide	5.6	0.02
Double-leaf with or without centre rebate	2 m high 1.6 m wide	9.2	0.03
Lift landing door (see **5.3.2.3**)	2 m high 2 m wide	8	0.06

For doors smaller than the above sizes the leakage areas given should be used. For doors larger, the leakage area should be increased in direct proportion to the increase in crack length. See also **5.4.3**.

For instance, a wide single-leaf door 2 m high and 1.2 m wide in a rebated frame opening into a pressurized space will have a leakage area of (6.4/5.6) × 0.01 m^2 = 0.0114 m^2 (i.e. an increase of 14 %).

Using the leakage areas given in Table 3 and the expression for calculation given in **5.3.1**, values of air leakage past closed doors given in Table 4 are obtained for the pressure differentials most commonly required for the design of a pressurization system.

5.3.2.2 *Windows*. Although in many instances the pre pressurized spaces will not be on an external wall and consequently will not have any window openings, there may be examples where a window opens out of a pressurized space. It is therefore appropriate to include typical leakage data for windows in Table 5.

Unlike doors, windows will vary considerably in size and for this reason the leakage areas given below are for unit length of crack. In determining the leakage round an openable window the total length of cracks should be measured and multiplied by the appropriate factor for unit length from Table 5.

5.3.2.3 *Lift landing doors*. Leakage of air past a lift landing door cannot be determined by simply using the leakage area of the lift door as given in Table 4 because the air leaks away from the lobby via the intermediate space of the lift shaft. In this case the air from the lobbies also pressurizes the lift shaft, flowing into the lift shaft at all floors. The overall flow will thus depend on the leakage paths (a) between the lobbies and the lift shaft and (b) between the lift shaft and the outside air (see Figure 7). These leakage paths are in series and the relationship expressing the total rate of airflow from all the rift lobbies via the lift shaft becomes

$$Q_F = 0.827 \times \frac{A_t \times A_F}{(A_t^2 + A_F^2)^{1/2}} \times P_L^{1/2} \qquad \text{...(13)}$$

where

Q_F is the total airflow into lift shaft (m^3/s),

A_t is the total leakage area between all lobbies and the lift shaft (m^2); (this is generally equal to n A_d where n is the number of pressurized lobbies opening into the lift shaft and A_d is the leakage area of one lift door),

A_F is the total leakage area between lift shaft and non-pressurized spaces (m^2),

P_L is the pressurization level of lift lobby (Pa).

The amount of air leakage from each lobby into the lift shaft can be determined by proportioning the total Q_F among all the lobbies in the ratio of each lobby's contribution to A_t. Where the leakage area is the same on all floors the air input to the lift shaft per floor is simply Q_F/n, where n is the number of pressurized lobbies opening into the lift shaft.

It is suggested that when pressurization is used in the lift lobbies a vent area of at least 0.1 m^2 per lift should always be provided.

Table 4 — Air leakage data for doors

Type of door	Leakage area	Air leakage in m^3/s					Value of *N* (see equation 1)
		Pressure differential in Pa					
		8 Pa	15 Pa	20 Pa	25 Pa	50 Pa	
	m^2	m^3/s	m^3/s	m^3/s	m^3/s	m^3/s	
Single-leaf opening into a pressurized space	0.01	0.0234	0.0320	0.0370	0.0413	0.0585	2
Single-leaf opening outwards from a pressurized space	0.02	0.0468	0.0641	0.0740	0.0827	0.0117	2
Double-leaf	0.03	0.070	0.096	0.111	0.124	0.175	2
Lift landing door (see **5.3.2.3**)	0.06	0.140	0.192	0.222	0.248	0.351	2

Table 5 — Air leakage data for Windows

Type of window	Crack area in m^2 per metre length	Air leakage in m^3/s per metre crack length for pressure differential in Pa					Value of N (see equation 1)
		8 Pa	15 Pa	20 Pa	25 Pa	50 Pa	
	m^2/m	$(m^3/s)/m$	$(m^3/s)/m$	$(m^3/s)/m$	$(m^3/s)/m$	$(m^3/s)/m$	
Pivoted, no weather stripping	2.55×10^{-4}	0.77×10^{-3}	1.15×10^{-3}	1.37×10^{-3}	1.58×10^{-3}	2.43×10^{-3}	1.6
Pivoted, and weather stripped	3.61×10^{-5}	0.11×10^{-3}	0.16×10^{-3}	0.19×10^{-3}	0.22×10^{-3}	0.34×10^{-3}	1.6
Sliding	1.00×10^{-4}	0.30×10^{-3}	0.45×10^{-3}	0.54×10^{-3}	0.62×10^{-3}	0.95×10^{-3}	1.6

For a specified size of opening from the lift shaft to the outside air the leakage from one lobby into the lift shaft can be calculated from

$$Q_d = \frac{Q_c \times F}{n} \quad ...(14)$$

where

Q_d is the leakage from one lobby past one lift door,

Q_c is the air leakage for an isolated lift door (value taken from Table 4 or calculated from $Q_c = 0.0496 \times (P)^{1/2}$ where P is the pressurization level for the lobby),

F is the factor depending on vent size in lift shaft and taken from the appropriate column of Table 6,

n is the number of pressurized lobbies opening into the lift shaft.

If a lift shaft connects a series of pressurized lobbies it should not have a door leading to an unpressurized lobby or space unless that space is not part of an escape route and has no door communicating with an escape route.

The above calculation relates to one lift and it is assumed that the lift shaft is protected. A separate calculation has to be made for each lift. When there are two or more lifts in a common shaft it is sufficient for the purpose of calculation to treat each lift as being in its own single shaft, in which case the value of A_F used should be that relating to each separate lift (usually A_F for the large common shaft divided by the number of lifts in that shaft).

5.3.2.4 *Other series and parallel leakage paths.* Similar combinations of series and parallel leakage paths may occur in other situations and the above methods (suitably adapted to take account of the particular circumstances) may be used provided all the spaces involved are structurally protected. Where the intermediate space is not a protected structure it should not be assumed that this space will remain pressurized and the method of assessing airflow requirements for pressurization should be based on equation (1).

5.3.2.5 *Toilet areas.* When toilet or other areas that are directly connected to a pressurized space have mechanical extract systems the leakage rate into them is either:

a) when the extract fan is running, taken to be the extract rate in cubic metres per second, or

b) when the extract fan is off, calculated from:

$$Q_G = Q_B \times K \quad ...(17)$$

where

Q_G is the leakage into the toilet (or other) space (m^3/s),

Q_B is the door leakage rate (m^3/s) at the design pressurization taken from Table 4 or calculated from equation (1), and

K is a factor depending on A_X/A_G taken from Table 7,

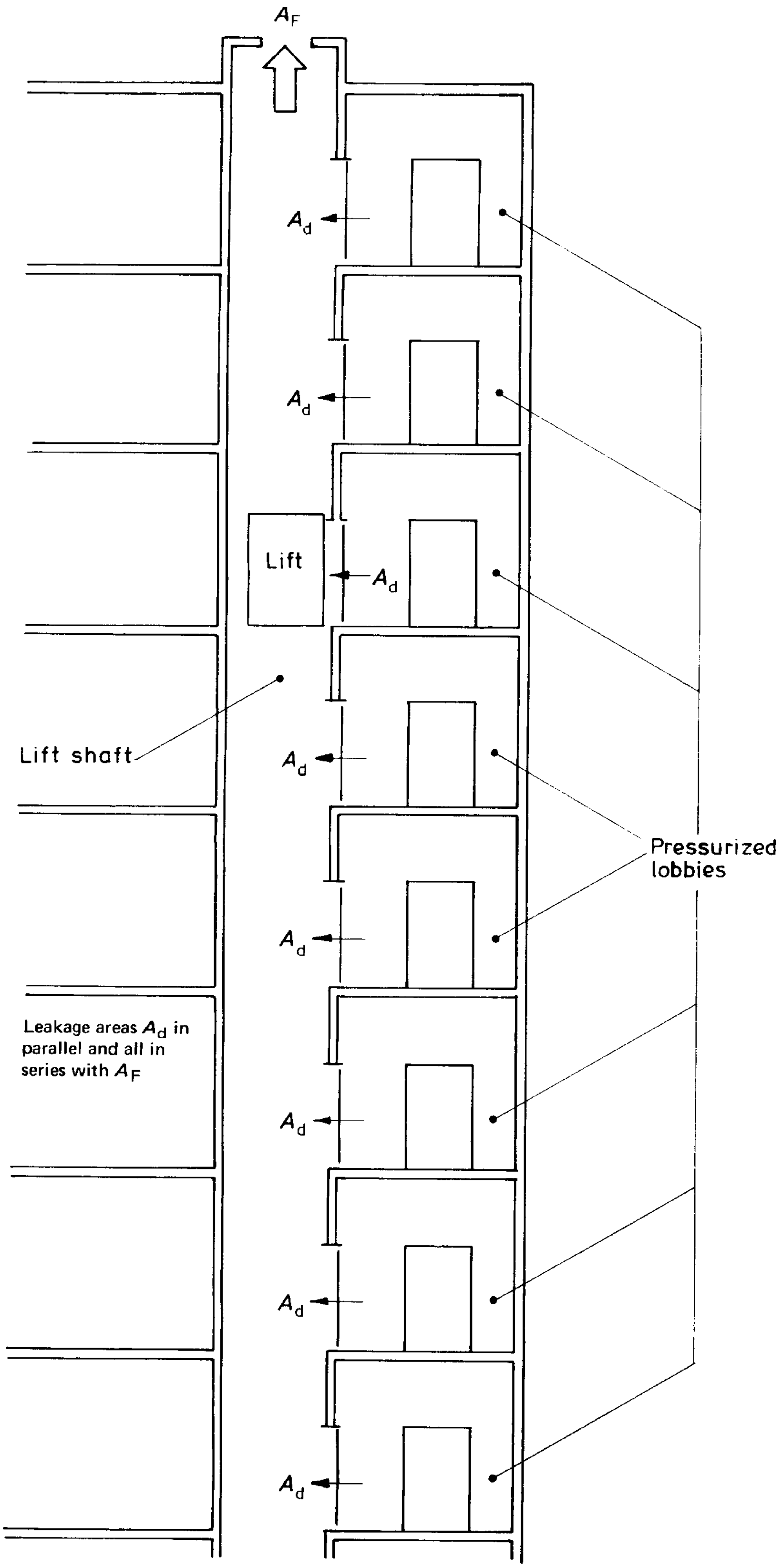


Figure 7 — Diagram of leakage from lift landing doors

where

A_x is the minimum cross-sectional area (m^2) of extract branch duct (this may be a duct cross section or the balancing device at the orifice or damper), and

A_G is the door leakage area including area (m^2) of any airflow grilles or large gaps for air transfer.

NOTE The value of A_G including airflow grilles and/or large gaps for air transfer has also to be used to calculate the value of Q_B when the leakage area is greater than the normal total area of cracks.

Table 6 — Values of factor *F* for various vent sizes

Number of pressurized lobbies opening into the lift shaft (= n, see equation 14)	Value for *F* for vent size:		
	0.1 m^2	0.16 m^2	0.22 m^2
1	0.86	0.94	0.96
2	1.28	1.60	1.76
3	1.46	1.99	2.32
4	1.54	2.22	2.70
5	1.58	2.35	2.96
6	1.61	2.44	3.13
7	1.62	2.49	3.25
8	1.63	2.53	3.33
9	1.64	2.56	3.40
10	1.645	2.58	3.44
12	1.65	2.60	3.51
14	1.655	2.62	3.55
16	1.66	2.63	3.57
above 16	1.66	2.66	3.66

NOTE 1 The figures in column 2 (vent size 0.1 m^2) should be used if the only opening from the lift shaft to unpressurized space is of this size. (This is the normal design situation.)

NOTE 2 The figures in column 3 (vent size 0.16 m^2) should be used if the vent size is larger than 0.1 m^2 by 50 % or if with a vent size of 0.1 m^2 there is one lift door leading to an unpressurized lobby.

NOTE 3 The figures in column 4 (vent size 0.22 m^2) should be used if the vent is larger than 0.1 m^2 by 100 % or if with a vent size of 0.1 m^2 there are two lift doors in the same shaft opening into unpressurized lobbies.

NOTE 4 If the lift shaft serves n pressurized lobbies opening into the lift shaft and in addition has doors opening into more than 2 unpressurized lobbies, a fresh calculation of F using equations (15) and (16) has to be made.

NOTE 5 Columns 3 or 4 would be used to calculate the air flow out of a lobby when a door in one lobby (column 3) has been left open of when two doors, one in each of two lobbies, have been left open (column 4).

NOTE 6 If there are additional leakage paths out of the lift shaft new values of the factor F should be calculated from

$$F = \frac{A_f}{A_d} \qquad \text{...(15)}$$

where

$$A_f = \left(\frac{1}{\left(\frac{1}{A_F}\right)^2 + \left(\frac{1}{n \times A_d}\right)^2} \right)^{1/2}, \qquad \text{...(16)}$$

= total effective leakage area of lift shaft,

where

A_d is the leakage area of one lift door,

A_F is the total leakage area between lift shaft and non-pressurized spaces (normally the area of the vent),

n is the number of pressurized lobbies opening into the lift shaft.

Table 7 — Values of *K*

A_X/A_G	K
4 or more	1
2	0.9
1	0.7
0.5	0.45
0.25 or less	0.25

5.3.2.6 *Unidentifiable leakage from pressurized space.* The design process for a pressurization scheme depends on identifying all the leakage areas out of the space to be pressurized. From a knowledge of the total leakage from the space a calculation is made of the air supply needed to maintain a pressure differential of the required level.

It follows that any space to be pressurized has to be so constructed that any leakage of air through the building fabric will be minimal.

If the construction is of concrete it will probably be satisfactorily leakproof but if the construction is of blockwork it will probably need to be rendered or plastered to ensure that it is leakproof.

Additionally, attention should be paid to joints between walls or between walls, floors and ceilings to ensure that no incidental leakage occurs at these places. This last precaution is likely to be particularly important if a system-built structure is involved.

In calculating the air supply needed for a pressurization system two major assumptions have to be made. These are:

a) that the leakage areas of the components (doors, lift doors and windows) that have been used in the calculations will apply to the components concerned when the building is completed;

b) that there are no unidentified leakage areas out of the pressurized spaces.

To allow for these two necessary assumptions it is suggested that 25 % should be added to the calculated values of the required air supply. It should be emphasized that this addition is suggested to make allowance for uncertainties in the values of the leakage areas that have been assumed. This addition is *not* intended as an allowance to take account of leakage in the supply ducting. The installer should make his own assessment of the likely leakage in his ductwork and make provision for this.

The calculated value of the air supply has to be delivered "in toto" to the pressurized spaces concerned and the approving authorities will have the power to require evidence that the actual airflow agrees with the calculated value.

5.3.2.7 *Large openings.* Design pressurization cannot be maintained if there are large openings between pressurized areas and neighbouring spaces; in these circumstances other aspects of smoke control may need to be considered.

When design pressurization cannot be maintained, smoke can be kept back from the opening provided the egress air velocity from the space (which would be pressurized if the opening were not large) is sufficiently high.

When the opening is permanent (i.e. is not a door opening intermittently) the air egress velocity would need to be 3 m/s to 4 m/s depending on the temperature expected from the fire (which will depend on the fire load and ventilation). For a low fire load likely to be well ventilated the lower air velocity will be adequate but for a high fire load the higher level should be used.

To obtain these velocities through large openings will require large volumes of air and this system of smoke control may well be uneconomic except for very special circumstances.

However, when the large opening is a door and it is reasonable to expect that it will be opened only intermittently and for short periods, lower air velocities will be acceptable. This situation is examined in **5.3.2.8**.

5.3.2.8 *The open door.* No escape route can be effective without doors giving access to it and it is inevitable that these be open from time to time. The design consideration for a pressurization system therefore needs to have regard to the fact that a door to a pressurized space may have to be open for short periods.

In **5.3.2.7** it has been stated that, although when a large opening is made between a pressurized space and the surrounding space a pressure difference cannot be maintained, the protection against smoke can be obtained by ensuring that a reasonable air velocity out through the large opening is maintained. For an intermittent opening such as a door, a lower air velocity than that suggested for the permanent opening can be used, and the value will depend on the position of the door. The requirements for the major situations are as follows.

a) If the staircase only is pressurized, with no intervening lobby, a minimum egress velocity of 0.75 m/s through an open door is necessary, and in a building of more than 20 storeys when two doors on different floors are open the same egress velocity through these doors is necessary. (Refer to Table 8, which gives examples of values of airflow for an open door not all of which meet this condition.) It is assumed that the pressurized staircase opens directly into the accommodation spaces from which there is leakage in accordance with the recommendations of **5.5**.

b) If the staircase and lobby on each floor are independently pressurized, a minimum egress velocity of 0.7 m/s is required when two lobby doors on one floor are open (this means a staircase/lobby door and a lobby/accommodation door open); this egress velocity may be at either of the open doors. When the building is of more than 20 storeys this condition should obtain when lobby doors on two floors are open. (Table 10 shows examples of values of airflow.) It is assumed that the pressurized lobbies open directly into the accommodation spaces from which there is leakage in accordance with the recommendations of **5.5**.

c) If the staircase and lobby on each floor are independently pressurized then, in addition to the requirement in b) above, one of the following conditions should also apply when the staircase/lobby doors are all closed and any one lobby/accommodation door is open. *Either* the egress velocity through the open lobby/accommodation door should be at least 0.5 m/s *or* the pressure differential across the corresponding staircase/lobby door should be within 5 Pa of the appropriate design value for the staircase pressurization level (Table 1). It is assumed that the pressurized lobbies open directly into the accommodation space from which there is leakage in accordance with the recommendations of **5.5**.

d) If the staircase only is pressurized and it opens into a corridor that serves several units of the accommodation, airflow through the open door that is recommended in a) should be achieved when one (or more) door(s) from the corridor to the accommodation is/are open and the leakage from each unit of the accommodation is in accordance with the recommendations of **5.5**.

e) If the staircase only is pressurized and it opens into lobbies and/or corridors that serve one or more units of the accommodation, the airflow through the open staircase door that is recommended in a) should be achieved when doors between the staircase and the accommodation are open in such a way that there is at least one path where there is no closed door between the staircase and the accommodation. The leakage from each unit of the accommodation should be in accordance with the recommendations of **5.5**.

f) If the independently pressurized lobby opens into a corridor that serves several units of the accommodation *and* the construction of that corridor is such that it will give a fire resistance of at least 30 min, then the airflow through the open door that is recommended in b) and c) may not be necessary because there is "three door" protection between the accommodation and the staircase.

g) If the independently pressurized lobby opens into a corridor that serves several units of the accommodation but the boundaries of that corridor are not of fire-resisting construction then the conditions for airflow through the open-door that are set out in b) and c) have to be achieved with one (or more) door(s) to the accommodation units open and each accommodation unit having leakage from it in accordance with the recommendations of **5.5**. Alternatively airflow grilles of a suitable size may be fitted between accommodation units, in which case the leakage recommended in **5.5** may be distributed among the accommodation units.

h) If at the design stage of a pressurized system the accommodation on each floor is undivided but is subsequently partitioned into separate units, airflow grilles should be fitted between the accommodation units.

Table 8,Table 9 and Table 10 assume infinite leakage and show that for the particular cases analysed in them the egress velocity conditions set out above have been automatically achieved for all but the smallest buildings when the spaces concerned are pressurized to the levels recommended in Table 1.

As part of the design calculations the designer should show the value of the egress velocity that will apply when doors, as dealt with above, are open. If the required egress velocities are not achieved as a result of the initial design, then the air input values to the staircase should be increased until these open-door conditions are satisfied. When this is necessary additional permanent opening(s) may have to be placed in the staircase to prevent the pressure rising above 60 Pa when all the doors are closed. This additional leakage area may be closed by a counterbalanced flap valve so designed that it will only open when the pressure exceeds 60 Pa. The flap valve would usually be placed between a pressurized space and an internal space. The calculated quantity of additional air should not be increased by the 25 % allowance for unidentifiable leakage recommended in **5.3.2.6**.

Table 8 — Airflow through an open door: staircase only pressurized: staircase/accommodation door open

Case 1. Staircase has single-leaf door from accommodation opening into stairwell on each floor plus double-leaf door to open air on ground floor and single-leaf door opening inwards to roof. Open door is assumed to have an area of 1.6 m^2.

Case 2. As case 1 but with double-leaf door to accommodation on every floor.

Building height	Number of storeys	Pressurization level	Airflow through one open door			
			Case 1		Case 2	
m		Pa	m^3/s	m/s	m^3/s	m/s
15	5	50	0.50	0.31	1.0	0.63
30	10	50	0.76	0.47	1.7	1.0
75	25	50	1.4	0.90	3.1	2.0
150	50	50	2.4	1.5	4.6	2.9

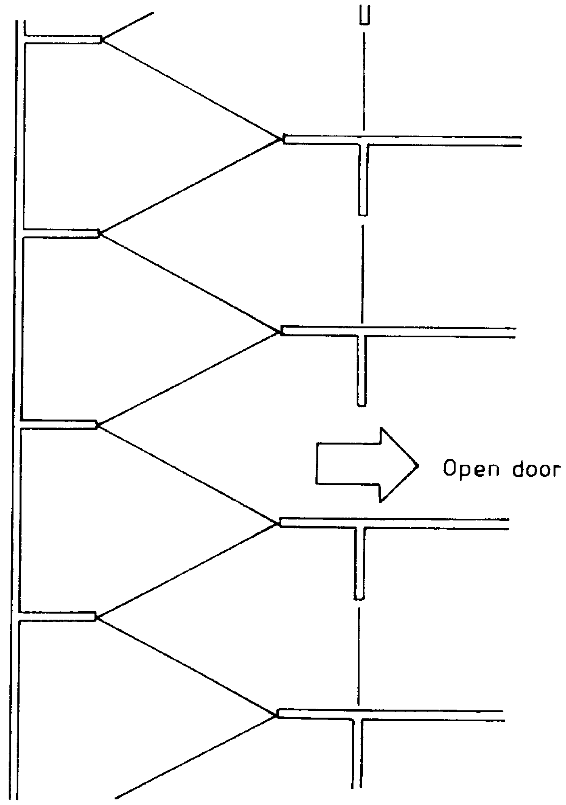


Figure 8 — Diagram of airflow conditions listed in Table 8

Table 9 — Airflow through an open door: staircase and lift lobby pressurized to same level: airflow when one lobby/accommodation door is open

Design conditions. Staircase has double-leaf door to open air at ground floor, single-leaf door to open air on roof. Single-leaf door at all levels between stairwell and lobby. Two lift entrance doors in each lobby and double-leaf door between lobby and accommodation.

Building height	Number of storeys	Pressurization level	Airflow through one open door		
			Pressure in other lobbies		
m		Pa	Pa	m^3/s	m/s
15	5	50	26	0.86	0.54
30	10	50	31	0.87	0.54
75	25	50	38	0.88	0.55
150	50	50	43	0.90	0.56

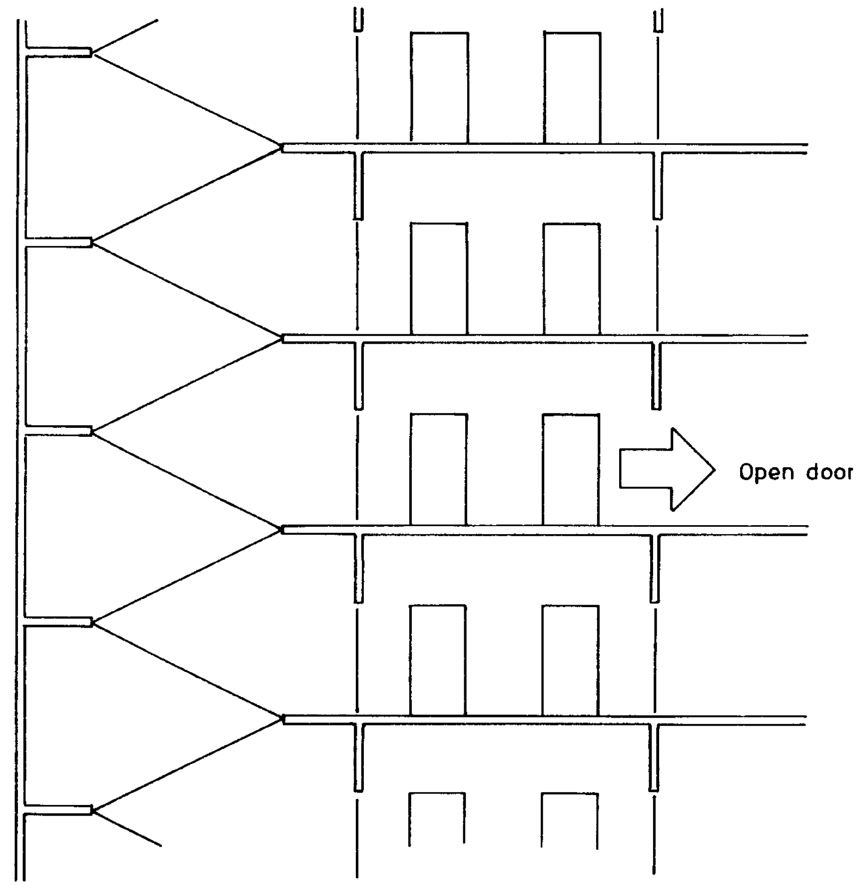


Figure 9 — Diagram of airflow conditions listed in Table 9

Table 10 — Airflow through two open doors: staircase and lift lobby pressurized to same level: two lobby doors (stairwell/lobby and lobby/accommodation) open on same floor

Design conditions. Staircase has double-leaf door to open air at ground floor, single-leaf door to open air on roof. Single-leaf door at all levels between stairwell and lobby. Two lift entrance doors in each lobby and double-leaf door between lobby and accommodation.

(The design conditions assumed are identical with those of Table 9.)

Building height	Number of storeys	Pressurization level	Pressurization level in other lobbies	Airflow through staircase/lobby door		Airflow through lobby/accommodation door	
m		Pa	Pa	m^3/s	m/s	m^3/s	m/s
15	5	50	20	0.42	0.26	1.20	0.75
30	10	50	23	0.62	0.39	1.37	0.85
75	25	50	25	1.24	0.78	1.96	1.23
150	50	50	27	2.30	1.44	3.01	1.88

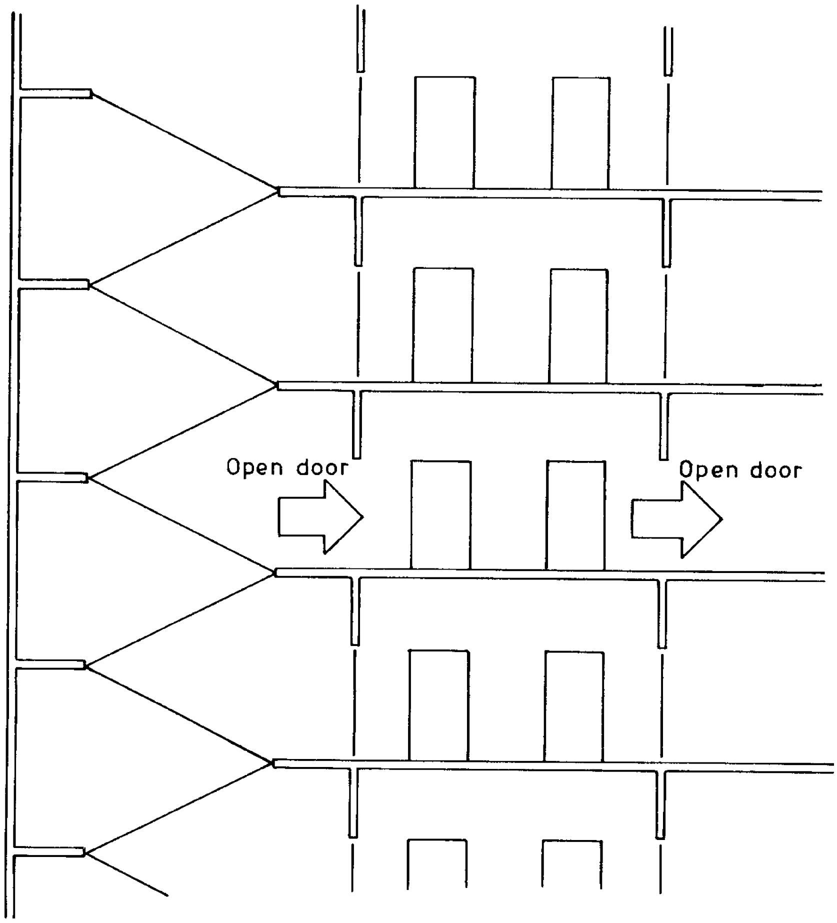


Figure 10 — Diagram of airflow conditions listed in Table 10

5.3.2.9 *Estimation of egress velocity through an open door (or other large opening).* The velocity actually attained in an open doorway when the venting recommendations of **5.5** obtain will be lower than that predicted for an open floor plan and for infinite leakage (as assumed in Table 8, Table 9 and Table 10). Therefore the velocity through an open door should be calculated for infinite leakage in the accommodation, using the methods given in **5.3.2.9.1**, **5.3.2.9.2** and **5.3.2.9.3**, and should then be multiplied by a factor 0.6 to yield a better approximation to the velocity that would be attained in practice when the venting recommendations of **5.5** are met. This factor should be used whenever airflows through an open doorway are calculated according to the methods outlined in **5.3.2.9.1**, **5.3.2.9.2** and **5.3.2.9.3** (see the worked example in Appendix A).

This procedure and the methods given in **5.3.2.9.1**, **5.3.2.9.2** and **5.3.2.9.3** for estimating the airflow past an open doorway are not exact, but are sufficiently accurate for the purpose and in many cases represent a very substantial simplification in calculation procedure. Uncertainties in the leakage resistance of actual systems do not justify a more sophisticated calculation procedure.

The volume of airflow past an open door derived according to the methods set out in **5.3.2.9.1**, **5.3.2.9.2** and **5.3.2.9.3** will be expressed in cubic metres per second.

It may be assumed that the open door will be a single-leaf door (or one leaf of a double-leaf door) and that its area will be 1.6 m^2.

To express the airflow past the door as an air speed in metres per second the values obtained for the volume flow should be divided by 1.6.

5.3.2.9.1 *Estimation of egress velocity: staircase only pressurized.*

a) For buildings of 10 storeys or less it is sufficient to assume that all the air input to the staircase will flow out of the open door. (The open door has been assumed to be single-leaf and 1.6 m^2 in area.)

b) For buildings of more than 10 storeys the leakage area of all of the other doors in the staircase (plus any other leakage areas) has to be totalled and the proportion of the input air that will flow out of the 1.6 m^2 door area calculated.

Example. If there are 20 storeys and 21 double-leaf doors leading out of the staircase the total leakage area through the remaining closed doors will be $(21 - 1) \times 0.03\ m^2$ and the proportion of air to flow out of the open door will be

$$\frac{1.6}{(1.6 + 0.6)} = 0.727.$$

5.3.2.9.2 *Estimation of egress velocity: staircase with lobby on each floor independently pressurized, one door (lobby/accommodation) open.*

a) *Lobbies not connected by lift shaft(s).* The total airflow out of an open lobby door will be the sum of

1) the air supplied to the lobby by the supply duct, and

2) the airflow past a closed door from the staircase into the lobby.

To calculate 2), it is sufficient to assume that the design pressure in the stairwell is maintained and that the pressure in the lobby with the open door falls to zero.

b) *Lobbies connected by one or more lift shafts.* The total airflow out of an open lobby door will be the sum of

1) the air supplied to the lobby by the supply duct,

2) the airflow past a closed door from the staircase into the lobby, and

3) the airflow out of each lift shaft past the closed lift entrance door.

To calculate 2), use the method given in a) above. To calculate 3), assume that the airflow into each lift shaft is still the value used in the design calculations. Then (roughly) one-third of this total air will flow into the lobby with the door from *each* lift shaft open. If there are two lobbies in the building with an open door then (roughly) only one-quarter of the total airflow into each lift shaft will flow into each lobby.

5.3.2.9.3 *Estimation of egress velocity: staircase with lobby on each floor independently pressurized, two doors (staircase/lobby and lobby/accommodation) on same lobby open.*

a) *Lobbies not connected by lift shaft(s).* The airflow past the door between the lobby and staircase will be the sum of

1) the air supplied to the staircase by the supply duct, and

2) all the air which will flow into the staircase past the closed doors from all the other lobbies.

The value of 2) is calculated using the formula

$$Q_T = Q_L \times \frac{A_D}{A_L} \times (n_S - 1) \qquad ...(18)$$

where

Q_T is the total airflow into stairwell from all the pressurized lobbies whose doors are closed,

Q_L is the air supplied by duct to one pressurized lobby,

A_D is the leakage area of the closed door between lobby and stairwell (assumed to be the same on all floors),

A_L is the total leakage area through which air leaks out of each lobby = $A_D + A_l$,

where

A_l is the leakage area of each lobby used in the design calculation,

n_S is the number of pressurized lobbies opening onto the staircase.

If two lobbies in the building have both doors open the air flowing through the staircase door to each lobby will be one-half of the total of 1) and 2) above and the factor ($n_S - 2$) should be substituted for the factor ($n_S - 1$) in equation (18).

The airflow past the second lobby door will be the total of

1) the air supplied to the lobby by the ducted supply, and

2) the airflow out of the staircase through the open staircase/lobby door (calculated as indicated above for one lobby or two lobbies with doors open as appropriate).

b) *Lobbies connected by lift shaft(s).* The airflow past the door between the lobby and staircase will be the sum of

1) the air supplied to the staircase by the supply duct, and

2) all the air that will flow into the staircase past the closed door from all the other lobbies.

The value of 2) is calculated using the formula

$$Q_T = Q_L \times \frac{A_D}{A_D + A_{l1} + \frac{m}{n} A_d F} \times (n - 1) \qquad ...(19)$$

where

Q_T is the total airflow into stairwell from all the pressurized lobbies whose doors are closed,

Q_L is the air supplied by duct to one pressurized lobby,

A_D is the leakage area of the closed door between lobby and stairwell (assumed to be the same on all floors),

A_{l1} is the leakage area of each lobby used in the design calculations excluding the leakage area of the lift doors,

A_d is the leakage area of lift entrance doors (usually assumed to be 0.06 m^2),

n is the number of pressurized lobbies opening into the lift shaft, *m* is the number of lift shafts opening into each lobby,

F is the factor listed in Table 6 for the appropriate number of storeys, using column 3 or column 4 of that table according to whether one lobby in the building has two doors open or two lobbies have doors open. In the latter case the factor ($n - 2$) must be substituted for the factor ($n - 1$) in equation (19).

Then the total airflow through the open staircase/lift lobby door will be equal to $Q_S + Q_T$, where Q_S is the air supplied by duct to the staircase.

The airflow past the open door between the lift lobby and the accommodation will be the sum of

3) the total airflow into the lobby from the staircase (i.e. $Q_S + Q_T$),

4) the air supplied by duct to each lobby (i.e. Q_L), and

5) the airflow out of all the lift shafts past the closed lift entrance doors.

The value of 5) is calculated using the formula

$$Q_A = \frac{m}{3} \; \frac{F \times A_d \times Q_L}{A_D + A_{11} + \frac{m}{n} A_d F} \qquad \text{...(20)}$$

where Q_A is the total airflow out of all lift shafts into a lobby with two open doors, and the other quantities are the same as those in equation (19).

When two lobbies each have two doors open, the factor *m*/3 in equation (20) should be changed to *m*/4, and column 4 of Table 6 should be used to determine the value of *F*.

The total of 3), 4) and 5) above, i.e. the total airflow past the open doors between lift lobby and accommodation, can be written

$$\text{Total airflow past door} = Q_S + Q_L \; \frac{A_I + n\,A_D + \left(\frac{m}{n} + \frac{m}{3}\right) A_d F}{A_D + A_{11} + \frac{m}{n} A_d F} \qquad \text{...(21)}$$

where Q_S is the air supplied by duct to the staircase and the other quantities are the same as those in equations (19) and (20).

5.4 Stipulations regarding air supplies. There are important conditions for the disposition and interconnection of air supply ducts and outlets for a pressurization system.

5.4.1 *Pressurization of staircase(s).* A separate pressurization system should be provided for each staircase.

The air supply to a pressurized staircase should be distributed evenly throughout the whole height of the staircase. Consequently, a single supply entry point is not acceptable unless the building has three storeys or fewer.

The air supply should be ducted up (or down) the staircase with outlet grilles at intervals not exceeding three storey heights between adjacent grilles. The outlets should be arranged and balanced so that equal quantities of air flow from each outlet grille.

5.4.2 *Pressurization of lobbies.* In general, lobbies may be pressurized using a common fan and duct system provided suitable balancing arrangements ensure that the correct air supply is provided to each lobby.

When the ambient pressure in one or two lobbies is disturbed because of open doors the reaction on the air supply to the other lobbies should be minimal (see **6.1**).

If the pressurization scheme consists of a staircase and associated lobbies a common pressurization fan system may be used for both staircase and lobbies but two duct systems should be used, one for the staircase and one for the lobbies.

If more than one staircase has access to a common lobby separate pressurization systems should be used for each staircase (as recommended in **5.4.1**). All or any of these staircase pressurization systems may be used to supply the lobbies provided a duct run is used for the lobbies that is separate from that used for the staircase.

5.4.3 *Importance of door clearance(s).* When a design for a pressurization system is being prepared assumptions need to be made regarding the leakage past doors, windows and other building components in order to specify the fan and ductwork required.

It is essential, therefore, to ensure:

a) that notwithstanding the information about door leakage given in **5.3.2**, the leakage areas summed are reasonable for the particular items (doors, windows, etc.) to be used in the building, and

b) that when fitted in the building these items conform with the leakage assumptions made.

A common difficulty arises in connection with the clearance at the bottom of a door. If, for example, because of a change in the thickness of floor covering, a large gap is left at the bottom of a door, this would not be regarded as important from the fire-resistance point of view, but it could have a major effect on the operation of a pressurization system. Such a change in floor covering could affect all the doors in a building.

5.4.4 *Fire dampers in the ductwork.* Since a pressurization system must continue to operate for the duration of a fire the duct work should be so positioned in the building as to enable the provision of fire dampers to be avoided. Ducts contained in protected shafts do not normally need to be fitted with fire dampers. (See **6.4.2**.)

5.5 The escape of the pressurizing air from the building

5.5.1 *General.* It is important to ensure that the pressurizing air can escape from the building in a way and at a place (or places) compatible with the design concept for the pressurization scheme. Care should be taken when partitioning to preserve the airflow.

There are four possible methods, A, B, C and D, that can be used and recommendations for each of these are given in **5.5.2**, **5.5.3**, **5.5.4** and **5.5.5**. If more than one method is used in one building, the requirement for the individual methods may be reduced in proportion to the amount of venting provided by each one. The vent sizes will be the same for above and below ground floors. The designer should consider local weather conditions.

In all of the tables and expressions given below

Q_N is the net volume rate of pressurizing air flowing into the floor, (excluding the air leakage to atmosphere via lift shafts and toilets) in m^3/s. The airflow figure for the door-open condition dealt with in **5.3.2.8** should be taken for this purpose.

5.5.2 *Method A: window leakage.* When the building has openable windows on every floor it is probable that the leakage through these will be sufficient to allow satisfactory venting of the pressurizing air. Table 11 shows the minimum total length of window cracks satisfactory for these purposes.

Adverse wind conditions. In assessing the available total length of cracks, one face of the building should be discounted because of possible adverse wind conditions. If the window leakage is not evenly distributed around the external wall, the side with the largest area of window leakage should be discounted.

5.5.3 *Method B: provision of special vents at the building periphery.* When the building is sealed or insufficient openable windows are available special vents should be provided on all sides of the building and the total effective area per floor should be not less than $Q_N/2.5\ m^2$ (for Q_N see **5.5.1**).

Adverse wind conditions. In assessing the effective area of venting required per floor, one side of the building should be discounted. If the venting is not evenly distributed around the external wall, the side with the largest area of venting should be discounted for the calculation.

Vent opening arrangements. It is unlikely that vents in the form of permanent openings will be acceptable for the normal use of the building, so that a vent design has to be used that ensures that the vent area is open when the emergency pressurization system starts operating. The necessary features of the vent opening(s) are that

a) the vent closure should be normally held (or should rest) in the closed position;

b) when the emergency pressurization system operates, the vent closure should be released so that the pressurizing air is free to escape without having to develop any appreciable pressure to do so;

c) the vent closure should be capable of being closed by the action of adverse wind on that particular face of the building.

If automatically controlled venting is proposed, it is preferable that the venting should take place on the fire floor only. On all other floors, although the pressurization on those floors is active, the vents should remain closed. However, design calculations should assume that venting takes place on all floors.

Table 11 — Minimum total length of window cracks (per floor) for satisfactory venting of the pressurizing air

Type of window	Recommended crack length in metres (see 5.5.1 for Q_N)
Pivoted, no weather stripping	1 200 × Q_N
Pivoted and weather stripped	8 300 × Q_N
Sliding	3 000 × Q_N

5.5.4 *Method C: vertical shafts.* If venting the pressurizing air by building leakage or peripheral vents is not possible, vertical shafts may be used for this purpose. The minimum sizes of shaft and vents that are acceptable for this purpose are:

Net vent area per floor (accommodation into shaft)

$$A_V = \frac{Q_N}{2} \ (\mathrm{m}^2) \qquad \text{...(22)}$$

$$\text{Shaft size} = A_V \ (\mathrm{m}^2) \qquad \text{...(23)}$$

$$\text{Top vent (shaft to atmosphere)} = A_V \ (\mathrm{m}^2) \qquad \text{...(24)}$$

For Q_N see **5.5.1**

For buildings more than 100 m high special consideration of the pressure losses through the duct and its openings may be necessary.

Adverse wind conditions. The difficulties due to adverse wind conditions can be readily avoided when vertical shafts are used because a vertical discharge (with a suitable cowl) can be arranged.

Vents permanently open. If the vents into the vertical shafts from the accommodation floor are permanently open either a separate shaft for each floor should be used or, if a common shaft is proposed, a shunt duct system to avoid smoke and fire spread between floors should be used. Fire dampers should not be fitted to a vertical shaft used for venting the pressurizing air.

Vents automatically opened. A vertical duct arrangement that uses a system in which the vents on all floors are normally closed by a fire-resisting closure and that, when the emergency pressurization system operates, opens *the vent on the fire floor only* is the most satisfactory and should be used if possible when a vertical duct is proposed. This allows a common duct to be used without risk of fire and smoke spread between floors and exploits the advantage of venting the pressurizing air on the fire floor only.

5.5.5 *Method D: mechanical extract.* The release of the pressurizing air by using mechanical extraction is a satisfactory method if suitable precautions are taken.

The extract rate per floor should not be less than Q_N m^3/s, this value to be attained when a free path exists through open doors to the pressurized space. The extract system (ducts and fan) should be capable of withstanding temperatures up to 500 °C for a reasonable period and smoke and fire should not be able to spread from floor to floor through the extract system. (For Q_N see **5.5.1**.)

This latter condition can be satisfied by having a separate extract system for each floor or by arranging for the ducts on all floors to be normally closed by a fire-resisting damper. When the emergency pressurization system operates, the damper closing the extract system opens on the fire floors only.

If this last arrangement, which is preferable, is used, then:

a) the ductwork should be constructed to the appropriate standard of fire resistance;

b) the rate of extract should be such that an extract rate of Q_N can be maintained on the fire floor. (For Q_N see **5.5.1**.)

5.5.6 *Summary of venting arrangements.*Venting arrangements are summarized in Table 12.

5.6 Design procedure to be followed. When designing a pressurization system for a building the following steps should be taken.

a) Consider the proposals for the building and indicate changes in layout that will be possible or necessary if pressurization is to be used.

b) Identify the spaces to be pressurized and consider any possible interaction between pressurized and unpressurized space.

c) Decide whether the system is to be single-stage or two-stage and select the levels of pressurization to be used for emergency operation and, if appropriate, for reduced-capacity operation (Table 1).

d) Identify all the leakage paths through which air can escape from the pressurized space(s) and determine the rate of air leakage through each for the appropriate pressure differential. The procedures set out in **5.3.1** and **5.3.2** should be followed.

e) Total all the air flows out of each pressurized space and increase this total by 25 % in accordance with **5.3.2.6**. This will give the air supply needed for each pressurized space.

f) The air velocity through an open door should be estimated using the appropriate procedure set out in **5.3.2.9**. If the conditions of **5.3.2.8** are not satisfied the air supply proposed should be increased.

g) The air supply as estimated in e) and f) has to be provided at the duct terminal (or terminals) in each pressurized space. The positions of the duct terminals should be discussed with the architect and the appropriate authorities.

h) The fan capacity and duct sizes should be decided by a competent engineer after due consideration of the additional recommendations set out in clause **6**. The position of the intake grilles should be agreed with the architect and any special protection required for the installation specified (clause **6**).

i) The escape of the pressurizing air from the building should be considered and the appropriate method of venting specified (**5.5**).

j) The operation of the system should be considered and the position of smoke detectors (if required) specified (clause **6**).

k) A note of the leakage areas assumed should be given to the architect, reminding him that these areas have to be achieved in the finished building.

l) A measurement procedure should be specified so that the satisfactory operation of the installation in the completed building can be established (clause **6**).

A worked example is given in Appendix A.

Table 12 — Suggestions for choice of venting system

Building layout	Windows	Ventilation	Venting system	
			Main methods	Additional or alternative methods (if required)
Open plan	Openable, not weather stripped	Natural	Natural leakage (window leakage)	—
	Openable, weather stipped	Natural or mechanical	Natural leakage or vertical shafts	Peripheral vents or mechanical extract
	Sealed	Mechanical	Peripheral vents or vertical shafts	Mechanical extract
Floors partitioned	Openable, not weather stripped	Natural	Natural leakage (window leakage)	—
	Openable, weather stripped	Natural or mechanical	Natural leakage or peripheral vents	Vertical shafts or mechanical extract
	Sealed	Mechanical	Peripheral vents	Vertical shafts or mechanical extract

6 The installation and equipment

6.1 The installation and equipment associated with a pressurization scheme consist of:

a) air intake arrangements;

b) fan with its electrical system;

c) distribution ductwork;

d) ductwork terminals, i.e. grilles, diffusers, etc.;

e) automatic sensing or manual switching devices for initiating the emergency state of the system;

f) arrangements for the release of the pressurizing air;

g) maintenance arrangements for all the equipment.

In all of these items special arrangements will need to be made to ensure that in the event of and during a fire the installation works and continues to work in order to provide the smoke control required of it. All items of the installation should be so designed and so placed that at no time can any part of them be threatened by a fire in the building. Installations should comply with the recommendations given in BS 5720.

6.2 The air intake arrangements. It is essential that the air supply used for pressurization should never be in danger of contamination by smoke from a fire in the building.

Any increase or decrease in inlet or outlet pressure due to wind effect will be communicated through the building, possibly modifying the pressure balances through it. It is therefore essential that the air pressure conditions for the pressurization air intake and exhaust are made substantially independent of wind speed and direction.

When a pressurization system is used in conjunction with a mechanical air distribution system in the building it is also essential that any effects of wind speed and direction should be the same on both systems.

The position of the air intake for a pressurization system should preferably be at or near ground level and should not be placed near a potential fire hazard. It is recommended that a ducted connection be inserted between the air intake and the fan inlet.

If the air intake is positioned at roof level it should be placed so that it is unlikely to be affected by rising smoke; for instance, it should be separated from smoke rising up the face of the building by an upstand wall, and should be placed at a lower level than the discharge point of any duct or shaft likely to discharge smoke during a fire in the building. It is suggested that such an upstand wall should extend for at least 1 m above the level of the air intake and similarly that the discharge point of any smoke duct should be at least 1 m above this level. The air intake and the discharge point should have at least 5 m horizontal separation.

If the building is pressurized by individual fans on each floor the air intakes should be positioned or designed so that the risk of smoke being drawn into the system is minimal.

In general, the air intake will probably be at the same level as the plant room and therefore the importance of placing the air intake at ground level should receive consideration when the position of the plant room is decided.

6.3 The fan with its electrical system

6.3.1 *Assessing fan duty.* The required fan duty should be assessed from the following:

Volume flow rate	Aggregated supply to all pressurized areas supplied by that fan, *plus* an allowance for probable leakage in the ductwork. The allowance for leakage to be added to the volume flow rate should be 15 % for sheet metal ducting and 25 % for builders' work ducting, unless an on-site test can ensure a lower level of leakage.
Fan total pressure	Total resistance of distribution system *plus* emergency pressurization level.
Fan static pressure	Fan total pressure *minus* velocity head at fan discharge.

6.3.2 *Stand-by plant requirement.* For buildings with a single staircase, duplicate fans and motors should be provided. For buildings with more than one staircase, single fans with duplicate motors should be provided.

If, however, the total air requirement for a pressurized space is made up from two or more separate supplies acting together, then no further duplication of equipment is necessary.

It should be noted that provision of a stand-by plant does not remove the necessity for proper maintenance arrangements.

6.3.3 ***Electrical supply and equipment***

a) The electrical supply cable should be run through the building in such a way that it is protected from attack from a fire anywhere in the building.

b) If an emergency power supply using an independent prime mover is provided for the building, automatic arrangements should be made to connect the pressurization fan and associated electrical equipment to the emergency power supply if it has to be used at any time.

c) If an independent emergency power supply is not provided for the building, an alternative electrical main intake from a substation different from that supplying the main building supply should be provided.

d) Whatever the electrical supply arrangements, the connections for the pressurization equipment should be such that if it is necessary to switch off the electrical supply to the building the electrical supply to the pressurization equipment will not be interrupted.

e) The electrical switching and other control equipment associated with the pressurization fan motor should be provided with the same protection from fire as indicated in a).

f) The following control arrangements are recommended.

1) The fan should be energized from an automatic smoke or fire detector system, including a sprinkler system where this is fitted, or from a manual call point. Switch-off arrangements for the fan should be independent of the detector system.

2) Manual start/stop controls should be placed in the following positions:

in the central building services control room;

in the pressurization plant room if this is remote from the central building services control room;

near the building entrance in a position agreed with the fire authority.

g) Electrical installations should be in accordance with the "Regulations for the electrical equipment of buildings", published by the Institution of Electrical Engineers.

6.3.4 *Protecting structure for the pressurizing fan.* The pressurization plant, i.e. the fan, the electric motor and any associated control gear normally placed adjacent to the motor, should preferably be housed in a plant room separate from the main services plant room. If it is in the same plant room as the other service equipment it should be separated from the other equipment by a fire-resisting enclosure having a minimum fire resistance of 1 h. Access doors to the pressurization plant room should have the same period of fire resistance and should be self closing. A generator should be protected in its compartment to the same standard as the fan.

6.4 The distribution ductwork

6.4.1 *General.* For multistorey buildings the preferred arrangement of a pressurization distribution system is a vertical duct running adjacent to the pressurized spaces. The distribution ducting should generally conform to the recommendations given in CP 413 and to the requirements of any relevant building regulations.

6.4.2 *Fire dampers in ductwork.* Building regulations and/or CP 413 may call for fire dampers to be installed in the branch ducts where they penetrate the vertical protective structural shaft. The operating conditions for a pressurization system should not lead to the closing of such dampers, but they could create a hazard in the case of pressurized lobbies if a random mechanical failure of a fusible link occurred when the pressurization fan started. To avoid this happening it is recommended that permission be sought to omit these fire dampers. The need for fire dampers can be avoided if the duct is situated wholly within a protected enclosure. Fire dampers operated by remote means, e.g. smoke detectors or fusible links placed outside the ductwork, should not be incorporated in a pressurization air supply system.

6.4.3 *Duct construction.* The ductwork used for the distribution of the pressurizing air should preferably be of sheet-metal construction and should have machine-formed longitudinal seams and have sealant applied to all transverse joints. This construction should be in accordance with specification DW 141 for ductwork, of the Heating and Ventilating Contractors' Association.

The sheet-metal ducting should be run in protected shafts. Builders' work ducts may be used provided such ducts are used solely for pressurizing air distribution and provided the internal surface is rendered to limit air leakage or a sheet-metal lining is used, or it is shown that the leakage level is satisfactory.

A pressure/leakage test should preferably be applied to the installation, whatever type of construction is used, but when builders' work ducting is used it is essential that a test be applied to ensure that the leakage will not exceed 10 % when the emergency volume of pressurizing air is being carried in the duct. The method of test should be that given in specification DW 141 for ductwork, of the Heating and Ventilating Contractors' Association.

The use of adhesive tape should not be relied upon for the long-term sealing of ducts.

The layout of the ductwork and the sizing of the main duct or manifold and of the branch ducts should be in accordance with standard design procedure, as set out in the several publications relating to the heating and ventilating industry, e.g. IHVE Manual of the Chartered Institution of Building Services or ASHRAE Guide and Data Book of the American Society of Heating, Refrigerating and Air Conditioning Engineers. The system should be regulated and the airflow rates set in accordance with the IHVE Commissioning Code Series A. In addition, the commissioning procedure should include measurement of the total airflow into each pressurized space (see **7.3**).

6.5 The duct terminals, grilles, diffusers, etc.

6.5.1 *Position in the pressurized space.* The position of the inlet air grille for the pressurization of a space is not critical. For pressurized lobbies it should not be placed close to the main leakage path out of the space and if the leakage is fairly evenly distributed around the space a central position for the air inlet grille should be chosen.

For staircase pressurization, there should be several air inlet grilles, evenly spaced throughout the height of the staircase and situated so that there is a maximum distance of three storey heights between adjacent grilles. (See **5.4.1**.)

6.5.2 *Terminal design.* When a common duct system serves several separate pressurized spaces it is important to ensure that when the pressure in one or more is disturbed because of open doors the reaction on the air supply to the others will be minimal.

If when a door to one lobby is opened the airflow to the other lobbies is reduced by 15 % the corresponding reduction in pressure differential in those other lobbies will be 30 %. This condition should be regarded as the maximum permissible and the duct terminals designed or chosen to ensure that it is not exceeded. To achieve this condition if the emergency pressurization level is 50 Pa a pressure drop of 50 Pa is required in the duct terminals.

6.6 The use of automatic sensing or manual switching for initiating the emergency state of the system

6.6.1 *Type of sensing or switching required.* The preferred system for initiating the emergency state of the pressurization is by automatic smoke detectors but in some occupancies the pressurization may be started by an automatic fire alarm system or by a manual call point system if these are installed in the building.

The choice of system should be as follows.

a) In occupied buildings with sleeping accommodation the alarm system for starting the pressurization should be by an automatic smoke detection system.

b) In occupied buildings without sleeping accommodation an automatic fire alarm system (e.g. heat sensor system) or a manual call point system (e.g. a "break glass" alarm system) may be used.

Arrangement should be made for testing fire alarm systems without necessarily operating the pressurization system.

6.6.2 *Position of smoke detector heads or other fire alarm (automatic or manual) points.* In buildings in which smoke detectors are installed only for the operation of the emergency pressurization system (see **6.6.1**) a smoke detector should be fixed on the low-pressure side of every doorway that leads from an accommodation space to a pressurized space.

The placing of the smoke detector head inside the pressurized space is not generally acceptable, but in blocks of flats it may be necessary to place smoke detectors in the common corridor.

In those buildings where other systems of fire alarm are permitted as alternatives to smoke detectors (see **6.6.1**) manual call points should be sited in accordance with BS 5839-1.

6.7 Arrangements for the release of the pressurizing air.

In buildings having an arrangement for the release of the pressurizing air that relies on the automatic operation of the venting device (see **5.5.3**, **5.5.4** and **5.5.5**) the signal that operates this device should be the same as that which starts the emergency pressurization fans. Separate sensors that operate the vents only are not satisfactory.

The whole of the automatically operated equipment that provides the venting of the pressurizing air from the building should be included in the maintenance procedure.

6.8 Maintenance procedure. The whole of the pressurizing equipment, which includes the smoke detector system or any other type of fire alarm system used, the switching mechanism, the fans, the emergency power supply arrangement and the automatically operated venting equipment, should be the subject of a regular maintenance procedure; attention to these items of equipment should be included in the maintenance schedule for the building services. The emergency operation of any system should be tested weekly to ensure that each fan operates. The pressure differentials should be checked annually in accordance with **7.2.2** and it may be possible to install permanent apparatus for this purpose. A check list of maintenance procedure should be provided by the professional consultant or installer responsible for the design of the system.

On every occasion that the maintenance procedure is carried out, the person responsible for the building should obtain signed confirmation of this, together with written details of any unsatisfactory feature found during the maintenance check.

7 General

7.1 Integration with other active fire-protection measures in the building. The purpose of other fire-protection measures installed in the building will almost certainly be the extinguishing of a fire should one occur; this is different from the purpose of pressurization, which will be to prevent the ingress of smoke into an escape route.

A considerable quantity of smoke may be produced in the early stage of a fire before a sprinkler or other automatic heat detection or extinguisher system is operated. For this reason it is recommended that the operation of any such system should not be the sole method of initiating the emergency operation of a pressurization system. The recommended methods are set out in **6.6.1** and **6.6.2**. If sprinklers or heat-detection or extinguishment systems are provided, they should be linked with the pressurization system.

7.2 Acceptance tests

7.2.1 *General.* The only satisfactory way of establishing that a pressurization installation is operating correctly and according to the design concept is to make physical measurements of the pressure differentials across closed doors and of the air velocities through open doors.

A test using cold smoke will demonstrate only the air movements in the building and, short of an actual fire test, a hot smoke test is almost impossible. However, cold smoke tests can sometimes reveal unwanted smoke flow paths caused by faulty construction.

The design criteria for a pressurization system contain an allowance for adverse weather conditions and because it cannot be ensured that such weather conditions will obtain on the selected day even a fire test cannot be regarded as completely satisfactory as an acceptance test.

Thus the acceptance test should consist of:

a) a measurement in all the pressurized spaces of the pressure differential between each space and the adjacent unpressurized space, all doors being closed (this may require the summation of pressure differences measured across sets of doors);

b) a measurement of the air velocity out of a representative selection of open doors that, when closed, separate the pressurized space and the accommodation space of the building.

The test should only be carried out when the building is completed, the air conditioning and pressurization systems balanced, and the whole system in working order, with every component functioning satisfactorily and directed by the initiating system into its correct emergency mode.

Where mechanical systems are used for normal ventilation or air conditioning it is especially necessary to ensure that the conditions set out in **4.6** are met. (It is normally advisable for the engineer responsible for the system to be present at the test(s).)

7.2.2 *Measurement of the pressure differentials.* The measurement of the pressure differential between the pressurized space(s) and the adjoining unpressurized space(s) should be carried out using an adjustable liquid manometer or other sensitive and properly calibrated device.

A convenient place to measure the pressure differential will be across a closed door; small probe tubes are led to each side of the door, one tube passing through a door crack or under the door. The two probes are then connected to the manometer by flexible tubes. It is important that the tube inserted through a door crack should pass through the crack and far enough into the space beyond for the open end to lie in a region of still air. It is suggested that this tube should contain an L-bend (at least 50 mm long) so that after insertion through the crack the tube can be rotated at right angles to the crack. This procedure will bring the open end into a region of still air.

It is important that the insertion of the probe tube in the door crack does not modify the leakage characteristic of the door, for instance by holding the door face away from the frame rebate. The position for the measuring probe should be chosen accordingly.

The full operating and measuring procedure is set out in the Manual for Regulating Air Conditioning Installations, BSRIA Application Guide 1/75, published by the Building Services Research and Information Association; the methods described in that publication should be followed.

7.2.2.1 *Attainment of the correct pressurization level.* If there is any serious divergence from the design pressurization level in any of the pressurized spaces the reason for this should be established.

There are three main reasons for failure to achieve the design pressurization level; these are as follows.

a) The rate of input of fresh air to the pressurized space is too low, and remains low even when substantial leakage paths are opened from this space to the open air, for example by opening doors and windows.

b) The leakage areas out of the pressurized spaces are greater than those assumed in the design calculation.

c) The leakage areas out of the rest of the building are insufficient. In this case the rate of input of fresh air to the pressurized space will be lower than the design value, but will increase if substantial leakage paths are opened, for example by opening doors and windows.

7.2.2.2 *Measurement of the air supplies to the pressurized space.* The measuring procedure to be used in estimating the airflow at any point in a ventilation duct system is described in the BSRIA manual cited in **7.2.2**; to determine the volume rate of airflow into any pressurized space the following steps are required.

a) Measure the total fan air supply volume rate of flow as described in section 3 of the BSRIA manual.

b) Subtract the system leakage as determined by the pressure leakage test, using the method specified in HVCA Specification DW 141 of the Heating and Ventilating Contractors' Association (see **6.4.3**).

c) Proportion the net airflow to the terminals from the measurements obtained during the regulating of the system (which should be carried out in accordance with the IHVE Commissioning Code, Series A, of the Chartered Institution of Building Services).

Measurement methods for estimating the airflow out of any single terminal of the system are described in the BSRIA manual and may be used as an alternative to the full procedure described above when tracing positions of inadequate air supply.

The measurement of air supply to the pressurized space should first be made with the doors leading to the pressurized space closed and with normal leakage from the accommodation. If the measured air supply is less than the design value, it should be measured again with substantial leakage paths opened between the pressurized space and the outside.

7.2.2.3 *The leakage paths for the pressurizing air.* If the measurements made under **7.2.2.2** show that the design input rate has been satisfactorily achieved in the installation, the reason for a low pressurization level should be sought in the leakage areas out of either the pressurized spaces or the unpressurized space.

The cracks around doors and windows should be examined, with special attention to the gap at the bottom of all the doors. If any of the door or window gaps are found to be unacceptably large they should be reduced in size.

If all the doors and windows are found to be normally close-fitting, the enclosure of the pressurized space should be examined for other leakage paths that were not identified for the original design calculations. Extra leakage paths found should be sealed or the air volume input rate should be increased to allow the correct value of the pressurization level to be achieved with the additional leakage paths effective.

Finally, the air leakage from the unpressurized spaces should be examined to ensure that this is in accordance with the values set out in **5.5**. If this is inadequate, the leakage should be increased to conform to the value recommended in that section.

If an excess leakage from a pressurized space is corrected by increasing the air input supply an increase in the leakage from the unpressurized space(s) may also be required.

7.2.3 *The tolerance permissible in pressurization level.*The measured pressurization level should not be lower than 80 % of the design value or greater than 60 Pa.

7.2.4 *Measurement of airflow through an open door.* This measurement should be made with a rotating vane anemometer or other suitable instrument properly calibrated, using the procedure described in BSRIA Application Guide 1/75 of the Building Services Research and Information Association.

The average velocity through an open door should be found by combining measurements at a sufficient number of points over the opening to ensure that vertical and horizontal asymmetry in the flow does not cause substantial inaccuracy. For high accuracy at least 10 measurements at uniformly distributed positions in the door opening should be taken and an average value obtained for the airflow : high accuracy will usually require stable wind conditions and an empty building.

7.3 Information to be made available

7.3.1 *To the approving authority.* The approving authority should be provided with full details of the installation. These should include:

a) full calculations showing the design criteria used;

b) full specification details of the equipment used;

c) complete plans showing position and protection of the fan and associated electrical control equipment, and the location of fresh air inlets;

d) constructional details of the ductwork and duct terminals used for the pressurization system;

e) any other relevant constructional information required by the authority;

f) full operational details describing in words *and* by diagram the exact sequence of actions that will occur in the pressurization system and in the normal ventilating system when a fire occurs in the building;

g) a complete maintenance schedule indicating the maintenance check needed for each item of the equipment and the frequency of this check.

h) on completion, the results of the tests carried out on the pressurization system.

7.3.2 *To the building occupier/owner.* The occupier/owner of the building should be provided with a clear description of the purpose and operation of the installation. This should include:

a) a clear description of the purpose of the installation;

b) a concise statement in words assisted by diagrams of the operation of the installation giving a clear indication of the sequence of events that will follow a fire alarm;

c) a description of the function of each individual item of the installation with an indication of where in the building each part is situated;

d) a complete maintenance schedule indicating the maintenance check needed for each item of the equipment and the frequency of this check (see **6.8.1**);

e) a check list in the maintenance schedule of the actions necessary for maintenance, together with a register book that will form a record of the maintenance carried out and in which any faults found are recorded. Any corrective actions needed should also be recorded in this register.

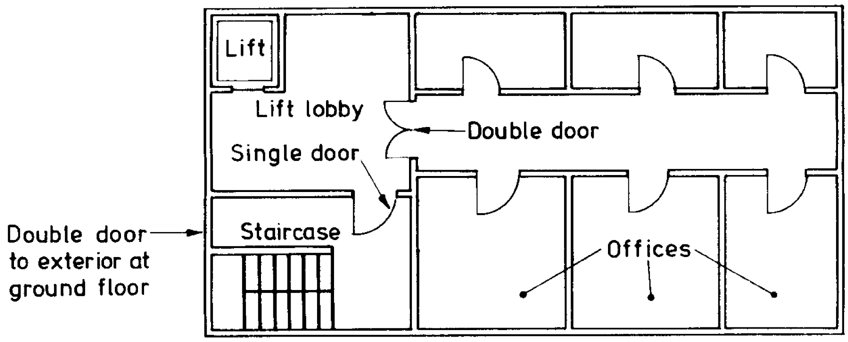
f) a set of drawings for retention on the site;

g) a warning that alterations to partitioning or floor coverings under doors may affect the operation of the pressurization system;

h) a recommendation to inform occupants that a pressurization system is installed and that, in the event of a fire, doors may be slightly harder or easier to open, and that there may be noise from the fans.

Appendix A A worked example

The following worked example is given to indicate how the code may be used. For clarity a very simple case has been selected.



NOTE. All six floors are similar except that the ground floor has a door to the exterior.

Figure 11 — Plan of building for worked example

To make the example easier to follow the relevant parts of the design procedure to be followed, given in **5.6**, are reproduced here.

a) *Consider the proposals for the building and indicate changes in layout that will be possible or necessary if pressurization is to be used.* In this example the possibilities for changing the layout arising out of the use of a pressurization system are not discussed.

b) *Identify the spaces to be pressurized and consider any interaction between pressurized and unpressurized space.* The staircase and lift lobby will be independently pressurized to the same level. (See **4.2.2.2**.)

c) *Decide whether the system is to be single-stage or two-stage and select the levels of pressurization to be used for emergency operation and, if appropriate, for reduced-capacity operation (Table 1).* A single-stage system is selected for this example with a pressurization level of 50 Pa.

d) *Identify all the leakage paths through which air can escape from the pressurized space(s) and determine the rate of air leakage through each for the appropriate pressure differential. The procedures set out in* **5.3.1** *and* **5.3.2** *should be followed.*

Staircase with 6 doors to lift lobbies. There is no pressure differential across any of the 6 doors leading to the lift lobbies, so no air supply is required for these.

1 double door to exterior:

leakage area $\simeq$ 0.03 m^2 (Table 3)

air leakage $\simeq$ 0.175 m^3/s (Table 4 for 50 Pa).

Alternatively from equation (2), the air leakage = $0.827 \times 0.03 \times (50)^{1/2} = 0.175$ m^3/s.

Lift lobby (each)

1 double door to accommodation:

leakage area $\simeq$ 0.03 m^2 (Table 3)

air leakage $\simeq$ 0.175 m^3/s (Table 4 for 50 Pa).

1 lift door into lift shaft:

door area = 0.06 m^2 (Table 3)

air leakage (uncorrected) = 0.351 m^3/s (Table 4).

If the lift shaft has a vent of 0.1 m^2 area then from Table 6 and equation (14)

$F = 1.61$ and

$$Q_d = \frac{0.351 \times 1.61}{6} = 0.0942\ m^3/s.$$

Alternatively from equations (16) and (15)

$$A_f = \left(\frac{1}{\frac{1}{(0.1)^2} + \frac{1}{(6 \times 0.06)^2}} \right)^{1/2} = 0.0935\ m^2$$

$$F = \frac{0.0935}{0.06} = 1.61$$

e) *Total all the airflows out of each pressurized space and increase the total by 25 % in accordance with* **5.3.2.6**. *This will give the air supply needed for each pressurized space.*

Staircase Airflow = 0.175 m^3/s

increasing by 25 % gives an air supply of 0.219 m^3/s

Each lobby Airflow = 0.175 + 0.0942

= 0.269 m^3/s

Increasing by 25 % gives an air supply of 0.337 m^3/s

f) *The air velocity through an open door should be estimated using the appropriate procedure set out in* **5.3.2.9** *If the conditions of* **5.3.2.8** *are not satisfied the air supply proposed should be increased*

TWO DOORS OPEN [**5.3.2.9**, case b)]

Staircase/lobby door

1) Air supplied to the staircase by the supply duct = 0.219 m^3/s.

2) Air that will flow into the staircase past the closed doors from all the other lobbies [equation (19)] is given by

$$Q_T = \frac{0.337 \times 0.01 \times (6-1)}{\left(0.01 + 0.03 + \frac{0.06 \times 1.61}{6}\right)}$$

$$= 0.300 m^3/s.$$

Then the total airflow through the open staircase/lobby door (assuming infinite leakage in accommodation)

= 0.300 + 0.219 = 0.519 m^3/s.

The total airflow through the open staircase/lobby door, corrected for resistance of leakage in accommodation

= 0.519 × 0.6 = 0.311 m^3/s.

Estimated velocity through door = $\frac{0.311}{1.6}$ = 0.19 m/s.

This value is less than the 0.7 m/s required by **5.3.2.8** c) but as either door may be considered it is not necessary at this stage to modify the design.

Lobby/accommodation door

1) Total airflow into the lobby from the staircase = 0.519 m^3/s (obtained above).

2) Air supplied by duct to the lobby = 0.337 m^3/s.

3) Airflow out of all the lift shafts into the lobby past the closed lift entrance doors [equation (20)]:

$$Q_A = \frac{1}{3}\left(\frac{1.61 \times 0.06 \times 0.337}{0.01 + 0.03 + \frac{1}{6} \times 0.06 \times 1.61} \right)$$

$$= 0.193\ m^3/s.$$

Then the total airflow through the lobby/accommodation door (assuming infinite leakage in accommodation)

= 0.519 + 0.337 + 0.193

= 1.049 m^3/s.

The total airflow corrected for the resistance of the leakage in the accommodation

= 1.049 × 0.6 = 0.629 m^3/s.

Estimated velocity through the door

$$= \frac{0.629}{1.6} = 0.39 \text{ m/s}$$

This is less than the 0.7 m/s specified in **5.3.2.8** b) so that in accordance with the last paragraph of **5.3.2.8** the air input values to the staircase must be increased.

The velocity required is 0.7 m/s, corresponding to a design air flow of

$$\frac{0.7 \times 1.6}{0.6} = 1.87 \text{ m}^3\text{/s}$$

This corresponds to an extra air supply to the staircase of 1.87 – 1.049 = 0.82 m^3/s.

This value should not be increased by 25 % to allow for unidentified leakage (**5.3.2.8**).

Then a first estimate for the area of the relief flap would be

$$\frac{0.82}{0.827 \times 50^{1/2}} = 0.14\text{m}^2$$

However, the rule by which the calculated air supply to a pressurized space should be increased by 25 % to allow approximately for unidentifiable leakage, means in this case the presumption that the leakage area from the staircase is 0.03 + 25 %. The area of the relief flap could therefore be reduced by 25 % of 0.03 m^2, i.e. by about 0.01 m^2 to 0.13 m^2.

This is a trivial correction in the present example, but if the example dealt with, for instance, a system in which only the staircase was pressurized and the effective leakage area from the staircase (and therefore the air supply to the staircase) was greater the correction could be significant.

ONE DOOR OPEN (**5.3.2.9**)

A check is now made to see that the conditions of **5.3.2.8** c) are satisfied.

1) Air velocity through open lobby/accommodation door (staircase/lobby door closed):

i) Air supplied to lobby by duct = 0.337 m^3/s.

ii) Airflow past closed door from staircase into lobby (Table 4) = 0.0585 m^3/s.

iii) Airflow out of each lift shall past the closed lift entrance door, taken as $^1/_3$ of the total airflow into the lift shaft (assumed to be the same as with the door closed) = $^1/_3$ × 0.0942 × 6 = 0.19 m^3/s.

Then the total flow through the open lobby/accommodation door, assuming infinite leakage in the accommodation = 0.337 + 0.0585 + 0.19 = 0.585 m^3/s.

The total flow corrected for the resistance of the leakage in the accommodation = 0.585 × 0.6 = 0.351 m^3/s.

The estimated velocity = 0.351/1.6 = 0.22 m/s.

This is less than the 0.5 m/s recommended by **5.3.2.8** c) and it is therefore necessary to check that the alternative recommendation is met.

2) Pressure differential across the staircase/lobby door is estimated as

$$\left(\frac{Q_s}{A_s \times 0.827}\right)^2 = \left(\frac{0.82 + 0.219}{(0.14 + 0.03 + 0.01) \times 0.827}\right)^2$$

$$= 49 \text{ Pa}$$

where

Q_s is the air supplied by duct to the staircase, and

A_s is the total effective leakage area from the staircase.

Thus the pressure differential requirement of **5.3.2.8**, with the tolerance allowed, is met, and no further modification to the air supply is needed.

g) *The air supply as estimated in e) and f) has to be provided at the duct terminal (or terminals) in each pressurized space. The positions of the duct terminals should be discussed with the architect and the appropriate authorities.* In this case a terminal would be required in each lift lobby and at least three evenly distributed in the staircase shaft.

h) *The fan capacity and duct sizes should be decided by a competent engineer after due consideration of the additional recommendations set out in clause* **6**. *The position of the intake grilles should be agreed with the architect and any special protection required for the installation specified (clause* **6***).* In this example the total supply to the pressurized parts of the escape route has to be

$$0.337 \times 6 + 0.219 + 0.82$$

$$= 3.06 \text{m}^3/\text{s}$$

and the quantity has to be delivered against a back pressure of 50 Pa.

The fan capacity will have to be greater than 3.06 m^3/s because there is likely to be duct leakage and the operating pressure is likely to be larger than 50 Pa because of duct and terminal pressure drops. The fan specification should then be chosen in conjunction with the requirement of clause **6**.

i) *The escape of the pressurizing air from the building should be considered and the appropriate method of venting specified* (**5.5**). In this example method B (**5.5.3**) is selected. Q_N, the net volume rate of pressurizing air

= 0.7 × 1.6 = 1.12 m^3/s (**5.5.1**)

hence the total effective vent area per floor should be

$$\frac{1.12}{2.5} = 0.45 \text{m}^2.$$

This should be distributed around the building, discounting one wall because of the effect of adverse wind.

In this case only three walls are available for venting, hence each wall should have an effective vent area of

$$\frac{0.45}{(3-1)} \text{ m}^2, \text{ i.e. } 0.23 \text{ m}^2.$$

j) *The operation of the system should be considered and the position of smoke detectors (if required) specified (clause* **6***).* In this example detectors would be fitted on the accommodation side of the lobby/accommodation doors, and possibly on the lobby side of the staircase/lobby doors.

k) *A note of the leakage areas assumed should be given to the architect reminding him that these areas have to be achieved in the finished building.* In this example special vents have been selected for venting so there should be little problem in ensuring the correct leakage area.

l) *A measurement procedure should be specified so that the satisfactory operation of the installation in the completed building can be established (clause* **6***).* In this example the following tests would probably be performed:

1) Measurement of pressure differential across staircase/lobby door. The value would be expected to be zero.

2) Measurement of pressure differential across lobby/accommodation door. The value would be expected to be at least 40 Pa but not to exceed 60 Pa.

3) With both lobby/accommodation and staircase/lobby doors open the velocity of air through the lobby/accommodation door would be measured and a value of 0.7 m/s expected. A selection of corridor doors would be open.

4) With the lobby/accommodation door open the pressure differential across the closed staircase/lobby door would be measured and a value between 40 Pa and 60 Pa expected. Measurements 1), 2), 3) and 4) would be made on every floor.

Publications referred to

BS 4422, *Glossary of terms associated with fire.*
BS 5588, *Fire precautions in the design and construction of buildings.*
BS 5588-1, *Residential buildings.*
BS 5588-1.1, *Code of practice for single-family dwelling houses*[3].
BS 5588-1.2, *Code of practice for flats and maisonettes*[4].
BS 5588-2, *Code of practice for shops*[3].
BS 5588-3, *Code of practice for office buildings*[3].
BS 5588-5, *Code of practice for firefighting stairways and lifts*[3].
BS 5720, *Code of practice for mechanical ventilation and air conditioning in buildings.*
BS 5839, *Fire detection and alarm systems in buildings.*
BS 5839-1, *Code of practice for installation and servicing.*
CP 413, *Ducts for building services*[5].

[3] Referred to in the foreword only.
[4] Referred to in the foreword only. This code will be a revision of CP 3: Chapter IV-1.
[5] Under revision. The revision of the main body of CP 413 will be published as BS 8313, and the revision of appendix A to CP 413 will be published as BS 5588-9.

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