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FIRE SAFETY IN ATRIUM BUILDINGS

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PREFACE

The need for this report was seen by the Building Research Association of New Zealand (BRANZ) as part of its ongoing involvement in fire protection, its research into building controls and its commitment to assist the Standards Association of New Zealand (SANZ).

ACKNOWLEDGEMENTS

BRANZ acknowledges the considerable assistance in gathering information for the writing of this report provided by code writing authorities and researchers overseas, and by those who made comments during drafting.

This report is intended for approving authorities, building owners, design engineers, architects, fire engineers and code writers.

FIRE SAFETY IN ATRIUM BUILDINGS

BRANZ STUDY REPORT SR15 D. BASTINGS

REFERENCE

Bastings D. 1988. Fire Safety in Atrium Buildings. Building Research Association of New Zealand, BRANZ Study Report SR15. Judgeford.

KEYWORDS

From Construction Industry Thesaurus, BRANZ edition: Alarms; Atrium buildings; Building Regulations; Codes of Practice; Construction; Means of Escape; Fire Risk; Fire Spread; Safety; Smoke; Standards.

ABSTRACT

A lack of requirements has been identified in the New Zealand Standard NZS 1900 Chapter 5:1988 Fire Resisting Construction and Means of Egress, relevant to fire safety in buildings containing atriums. This report examines overseas codes and regulations, and references recent research into smoke spread calculation methods. It proposes code requirements considered to be suitable for use in New Zealand until such time as NZS 1900.5 is revised.

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PART 2

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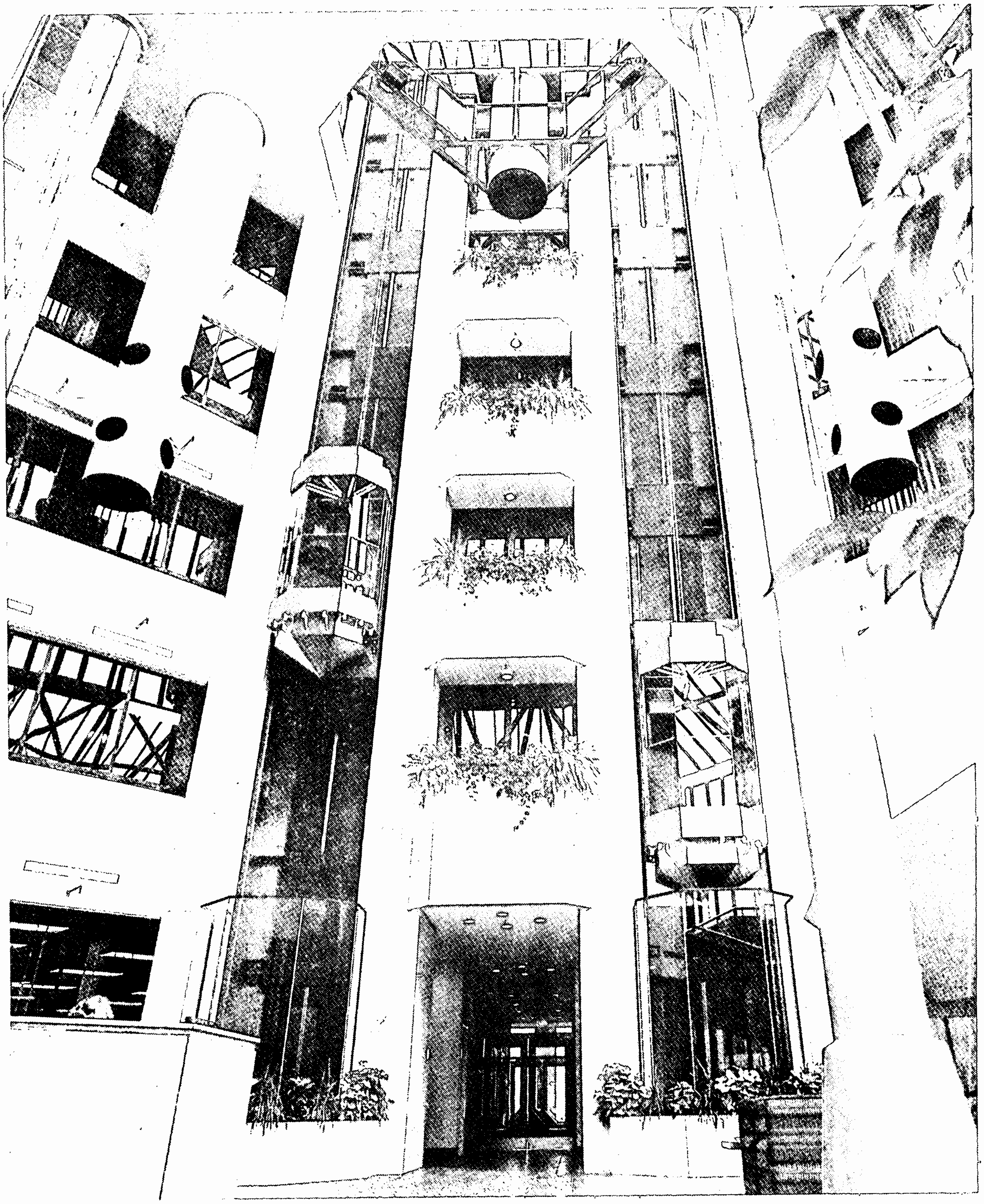


Photograph: John Pettit for Architecture New Zealand

Anchor House, Hamilton

SCOPE

This report is in two parts.

Part 1 is a review of the state-of-the-art with regard to fire safety in atrium buildings. It identifies that there is a lack of adequate requirements in NZS 1900 Chapter 5: 1988 Fire Resisting Construction and Means of Egress (NZS 1900.5) for such buildings. This Part is therefore a study of relevant overseas codes and information.

Part 2 contains recommended code requirements for interim use until such time as NZS 1900.5 is either revised or amended to include requirements for atrium buildings. The state-of-the-art is still developing, so there are drawbacks to making requirements that are too restrictive. However, approving authorities need guidance on how to approach the assessment of designs submitted to them, and designers need to have some basis on which to work.

PART 1

BACKGROUND

Many atrium buildings have been constructed overseas. Atriums have become popular because they are attractive as a means of allowing daylight into lower levels and creating an outdoor atmosphere which is protected from the extremes of climate. An atrium can contribute to visual appeal, achieve economies in the use of heat and light, and can provide recreational space. There is little doubt that an atrium can be a pleasant space to be in (see illustration of Anchor House, Hamilton, opposite page), particularly if it contains greenery.

However, atrium buildings contain features that can be a danger to the lives of occupants in the event of a fire. The presence of a large shaft unenclosed by fire resisting construction extending up through the floors of a multi-storey building is contrary to the principles and practice of compartmentation applied widely throughout the developed world. Conventional regulatory requirements for protected shafts and compartmentation are intended to limit smoke and fire spread to the floor of origin, but a fire occurring on the atrium floor level is likely to fill the atrium shaft with smoke, and fire spread floor by floor is just as possible inside an atrium shaft as up the external facade of a building. Using the atrium space as part of the escape route in the event of a fire can be uncertain at best and could be fatal at worst (Figure 1.1). It appears undesirable to have escape routes in this space, yet many atrium buildings existing overseas make a feature of open balconies from which the occupants can view the space below, and which are used for access. Conflicts such as these, between what is desirable and what is safe, are not new to the building industry throughout the world. Fire spread and smoke-logging can be accentuated by an atrium and major solutions to this problem include control of fire development by sprinklers, and improved life safety by extracting smoke and by protection of escape routes. A number of national codes and regulations have adopted

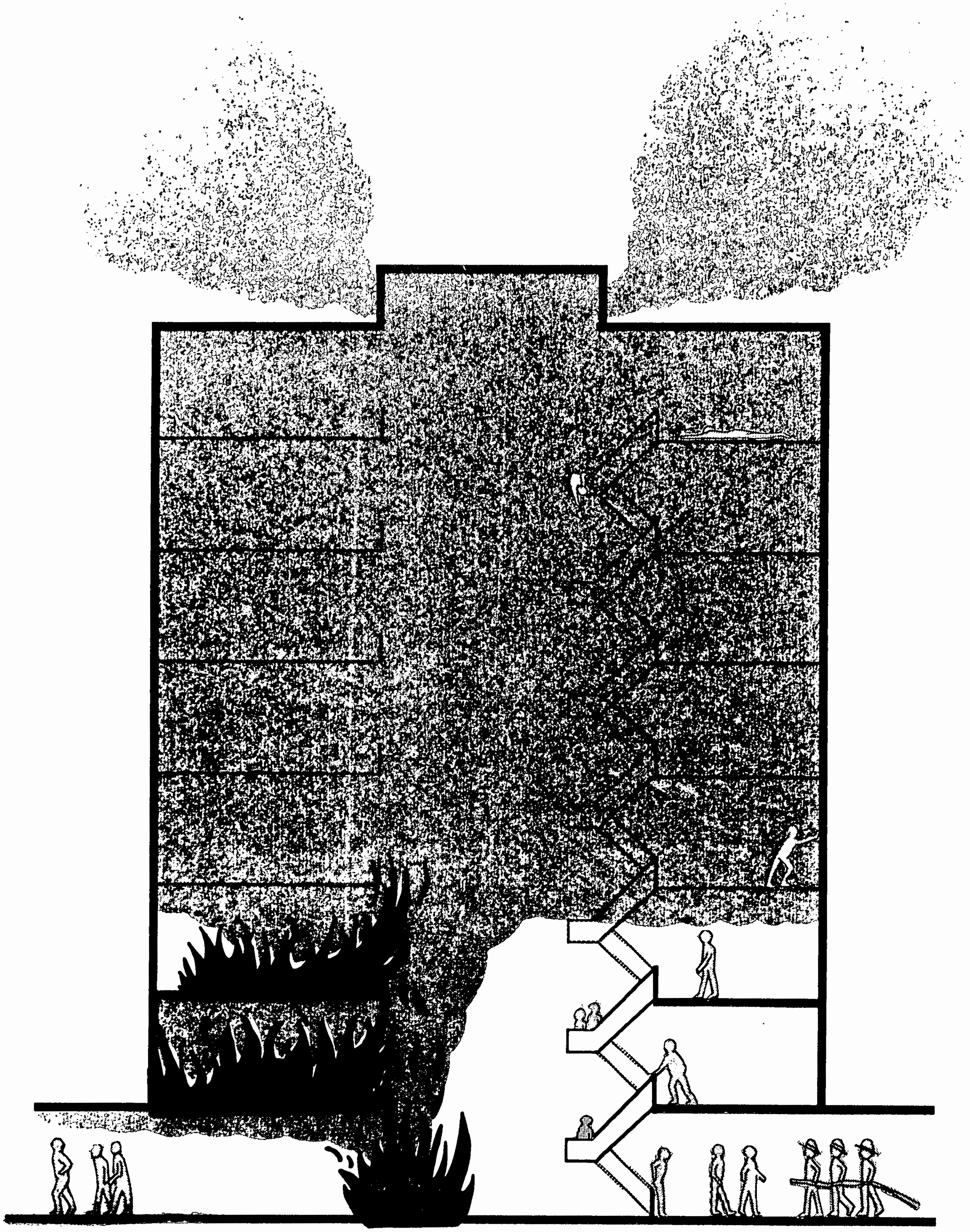


Figure 1.1   Unrestricted Fire & Smoke Spread

measures designed to make atrium buildings safe in the event of fire, but doubts have been expressed on the effectiveness of some of these measures.

A small number of buildings containing atriums have already been constructed in New Zealand, and more have been proposed. NZS 1900.5 contains no guidance on the fire safety problems peculiar to atrium buildings, and the only common denominator appears to be the New Zealand Fire Service Bulletin 1/85 which was written for internal use by the New Zealand Fire Service (see NZFS in Building Codes and Regulations at the end of Part 1 where the abbreviations used for the codes considered in this report are listed). The atrium buildings that have been completed appear to have been permitted by the approving authorities on the basis that they are safe because they have sprinkler systems, and that ventilation is provided to remove smoke. Decisions have been made on individual proposals, and judgements appear to have been based on the current awareness of the literature available to the authorities involved. In the opinion of Rae (1987) the full potential of the atrium in a recent New Zealand building may have been lost because the approving authority did not permit use to be made of the atrium space other than for circulation.

It is clear that New Zealand building controls are deficient because of this lack of published guidance. The motivation for this Study Report was to outline the fire safety problems, to discuss overseas solutions both by way of code provisions and by research, to compare and contrast current requirements overseas, and to propose code clauses suitable for use in New Zealand.

WHAT IS AN ATRIUM?

An atrium within a building is a large space which connects openings in floors, and which is wholly or partially enclosed at the top by a floor or roof, and which is used for purposes other than those normally associated with the small shafts commonly enclosing stairways, lifts and services. Should smoke enter such small shafts, the vertical smoke flow velocity may be high, whereas in large shafts of a size typical of atriums the velocity is low. The essential difference between an atrium and a traditional inner courtyard is that the atrium is roofed over, and smoke from a fire cannot readily escape to the outside atmosphere.

There is some variation between established codes on the definition of an atrium. Of the codes referenced in this report, three specify that an atrium shall be two or more storeys, and four define it as having more than two storeys, i.e., 1-2 stories are excluded. In this report the latter definition is used since many shopping malls are of one or two storeys, and it is thought better to differentiate between malls and atriums because of the differing life safety problems involved. Designers seeking guidance on fire safety design for shopping malls are well served by several references that have been available for some years (see Morgan 1979 and the references listed therein).

TYPES OF ATRIUMS

The sides of the atrium shaft may be open, or closed, and different fire safety problems and solutions may evolve from the way in which the architect chooses to handle this feature. Hansell (1986) identifies four types of atriums which relate to available options for control of smoke spread in each, as follows:

The fully open atrium: where the building has its upper levels open to the atrium shaft (Figure 1.2a).

The partially open atrium: where the building has some of its lower levels open to the atrium shaft, and the remainder closed off (Figure 1.2b).

The closed atrium: where the atrium shaft is separated from the remainder of the building by ordinary (not fire-resistant) construction. The atrium floor space may contain fire load, so it can be used for recreation, restaurants, or as a hotel lobby (Figure 1.2c).

The "sterile tube" atrium: where the atrium shaft is separated from the remainder of the building by fire-resistant construction. The shaft can have no function other than a way for daylight to penetrate, and the atrium floor can be used only for circulation and it must not contain any combustible material (Figure 1.2d).

SPREAD OF FIRE AND FIRE RESISTANCE

In a conventional, compartmented building the assumption is apparent in most building codes that a fire will be contained within the floor of origin. Further, it became evident during research for the Draft New Zealand Standard: Design for Fire Safety DZ 4226, 1984 (see also Bastings, 1988) that fire spread up the facade of a building by flame protrusion out the windows and into the floor above may not be prevented by current code requirements for spandrels, and therefore it is possible that a further floor above the fire floor may become involved before the Fire Service is in a position to control spread. It is therefore evident that fire spread, may occur up the sides of the atrium shaft, and that the problems of controlling this are similar to those presented by the external facade.

The levels of fire resistance needed in the structure can be determined by the conventional means of compliance with code requirements, which are likely to be conservative but safe. They may also be arrived at by the application of fire engineering principles. Consideration of the fire resistance requirements of atrium buildings is not pursued in this report, except where methods referenced provide information on likely gas temperatures which can form a basis for a fire engineering analysis of the structure, or where there is a need for fire separation of the atrium shaft from the rest of the building.

Current code requirements include provisions for safe escape routes for occupants within which they are protected from the effects of fire during their travel to a safe place. Thus, assuming that occupants have escaped from the fire floor, and from other floors adjacent to it, the Fire Service's action is to minimise property damage, once it is satisfied that lives of occupants are no longer at risk. In the case of an atrium building, this problem and the response to it, is similar to that of a

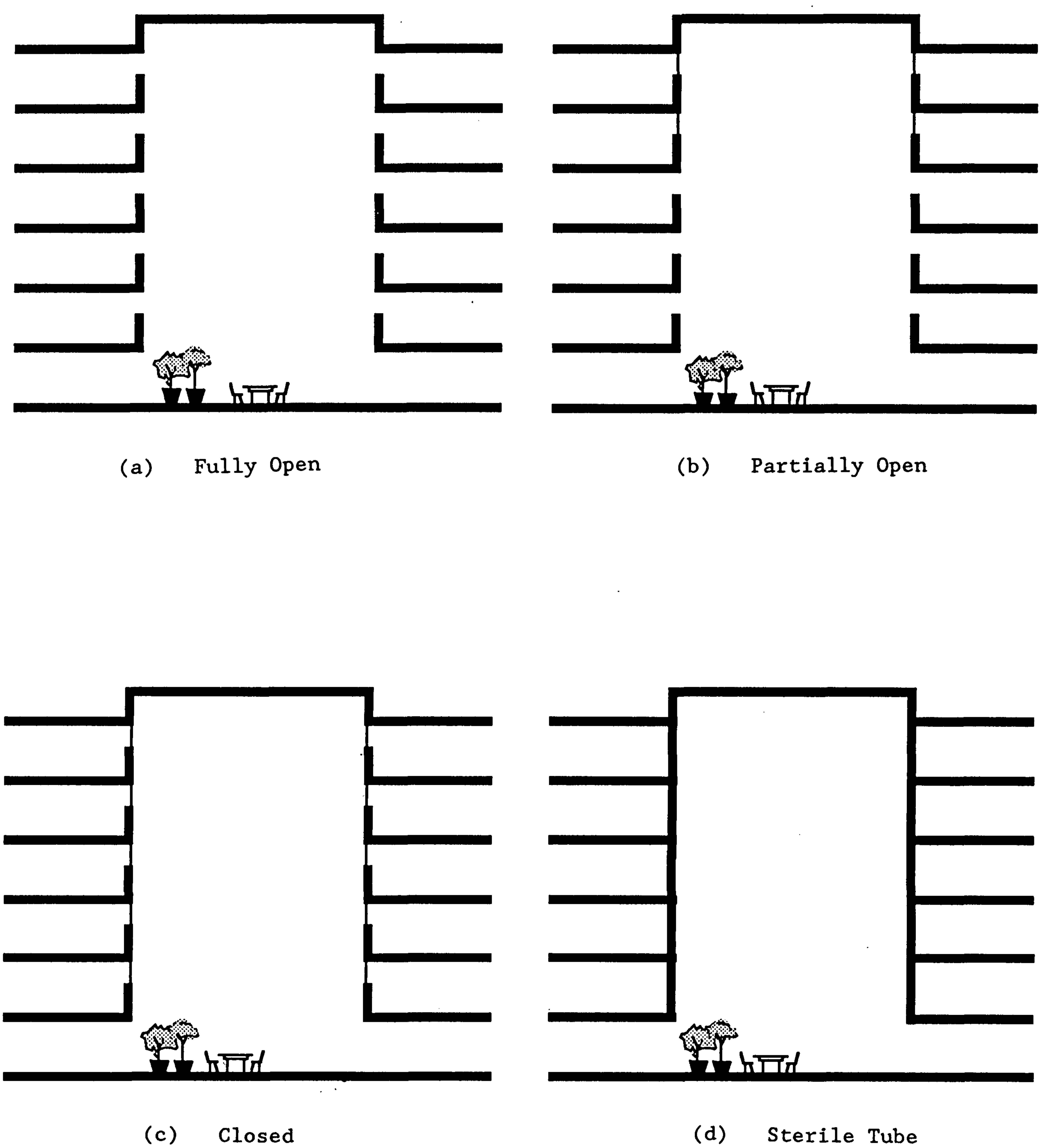


Figure 1.2: Types of Atriums

compartmented building, except that there is greater potential for fire spread in an atrium building. It is clear from all the references studied, that controlling the spread of fire in atrium buildings is a lesser problem than the hazard to life safety caused by spread of smoke.

SMOKE SPREAD AND REMOVAL

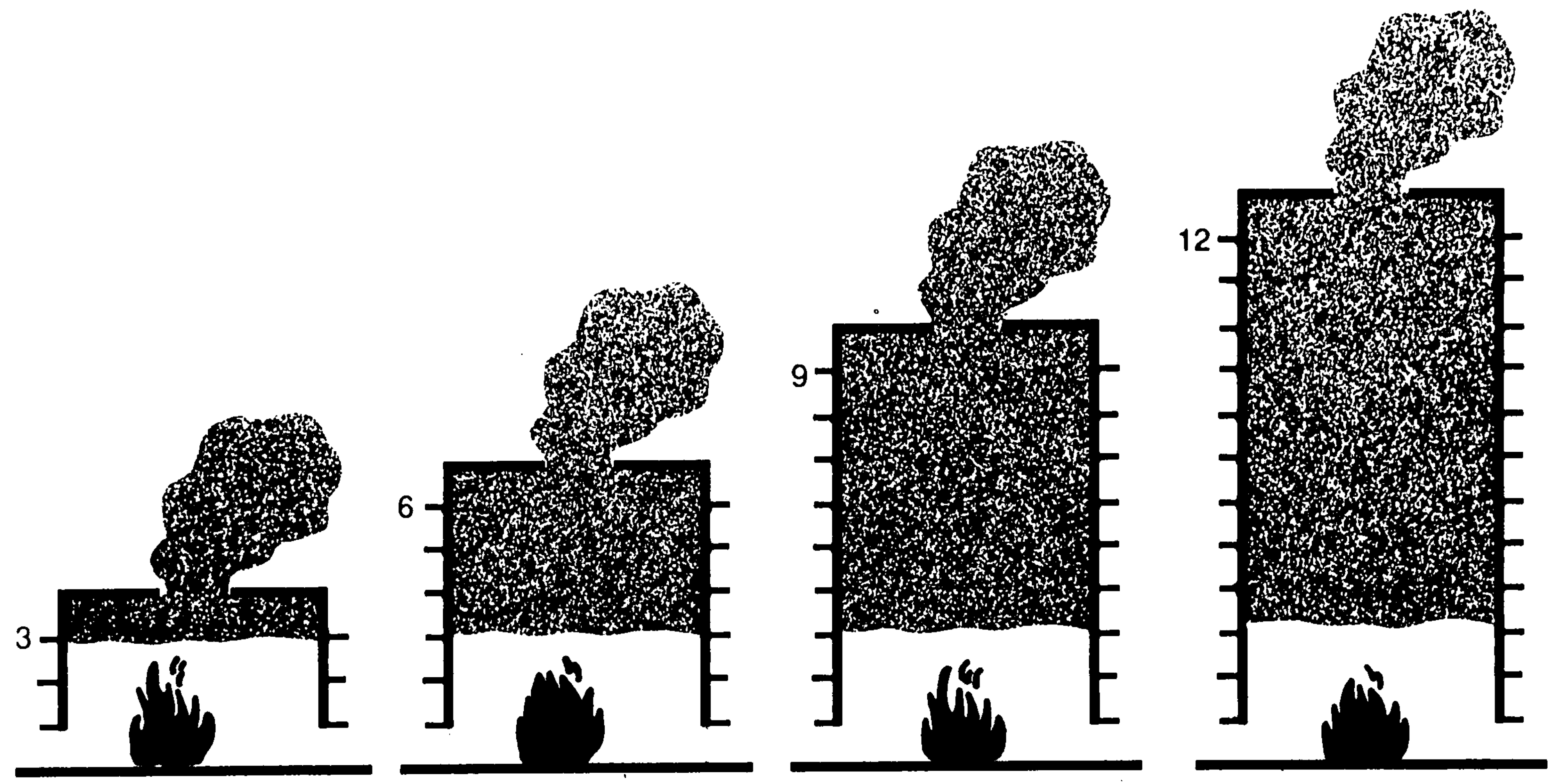
Several codes, including NFPA (1986), NZFS (1985), UBC (1985) and SBC (1985), permit atriums in most occupancies, except where a high fire risk applies. However, GLC (1980) prohibits them in sleeping occupancies, i.e., hotels etc, and NBCC (1985) does not permit them in hospitals. These prohibitions reflect a concern about the hazard from smoke to occupants whose response may be slow. Fires can rapidly generate a large volume of hot smoke which will rise and spread outwards, and at the same time become diluted with many times its volume of cold air. A fire occurring in the lower floors can fill much of the building volume with smoke in a time scale well within that needed for escape by the occupants of a tall building. There are various options available for smoke control and the choice of which one is appropriate will depend on the type of atrium.

It is clear that it is inadequate to rely only on dilution of the smoke by mixing with the volume of air contained in the atrium shaft, no matter how large this may be. Cold air will be entrained by the hot gas as it rises in the atrium shaft, reducing its density, and thus its buoyancy. At some height it will cease to rise by its own buoyancy, but can still spread sideways. This loss of buoyancy will tend to cause stagnation of the smoke mass, which will only be forced upwards by the pressure from further smoke arriving from below. Under this regime, Butcher (1986) points out that there is an upper limit of about four storeys for the height within which natural venting from the top of the atrium shaft can be relied on to extract smoke. Assumptions on the size of the design fire become important in this context, and this is discussed later.

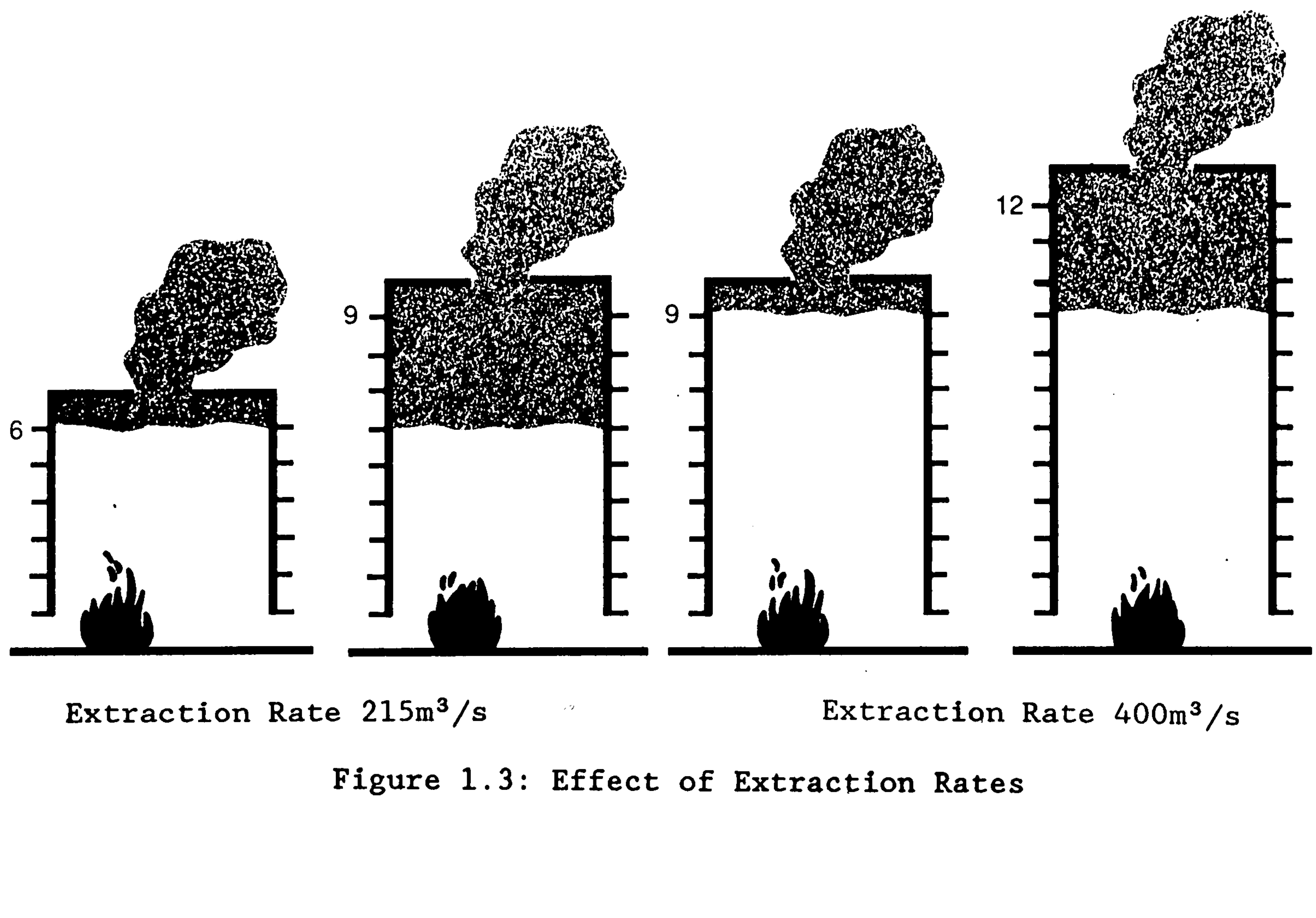
Ventilation openings are necessary at the top and bottom of an atrium shaft so that when a quantity of hot gas enters the shaft a stack effect is created. In order for hot gas to escape from the top openings, the pressure inside at the high level must be greater than the external atmospheric pressure. Similarly, for fresh air to flow inwards at the low level, the pressure inside must be less than outside. Thus, somewhere up the building there will be a neutral pressure plane where the pressure inside is equal to that outside. Any openings located in the sides of the shaft at this neutral plane would have no airflow through them as there will be no pressure differential. Where the inlet area is equal to the exhaust area, the neutral pressure plane will be approximately midway up the building.

The neutral plane is always higher than the base of the buoyant smoke layer. If an adjacent space has large openings to the atrium, it is effectively part of the atrium. If these large openings lie above the layer's base the adjacent spaces will fill with smoke, and the position of the neutral plane will not affect this. If the openings on to the atrium are small, there will be little smoke entering those adjacent spaces if the openings are below the neutral plane, even if they are above the layer's base. Therefore, there exists a potential for a designer, by varying the location and area of ventilation at the top and bottom of the atrium shaft, to manipulate the height of the neutral plane in relation to openings between the floors and the atrium shaft. Hansell (1986) provides details on how such designs can be carried out.

Where the atrium is fully open, fire occuring on any floor will result in smoke spreading into the shaft. Whether it will then spread to other floors will depend on the position of the neutral plane. Figure 1.3, which is based on Figure 2 of Butcher (1986), demonstrates how smoke accumulating downwards from the top of an atrium shaft is affected by the ventilation characteristics of the building. If the fire originates on the



Extraction Rate $85m^3/s$



Extraction Rate $215m^3/s$ Extraction Rate $400m^3/s$

Figure 1.3: Effect of Extraction Rates

atrium floor, or on one of the floors immediately above it, it is likely the rising smoke will bypass some of the lower floor levels, and spread laterally only into the upper levels. Buildings which permit this to happen seem to subject occupants to an unacceptable risk, yet the fully open atrium is probably the commonest type built. It appears that in some countries great reliance is placed on other measures aimed at minimising this risk.

With a partially open atrium shaft, an improved level of safety of occupants is apparent, at least for those situated on the floors that are enclosed. Should an architect wish to adopt this type of atrium, then the application of smoke extraction calculations would be necessary to determine the likely position of the neutral plane, and to ensure that it is located within the zone of the enclosed floors.

The closed atrium represents a further advance in providing protection for occupants against smoke spread. Enclosing the whole of the perimeter of the shaft will inhibit escape of smoke from the shaft to adjacent floors. If glazing is installed to permit viewing and entry of light, the glass may shatter after being exposed for some time to hot gases on one side only, and thus permit entry of smoke to the adjacent floor spaces. Most codes require drenchers or wall sprinklers to prevent this. Provided the enclosures are tight, it is probable that little smoke will leak through, and the amount that does, will become so diluted as to present little reduction in visibility. Should the fire occur on an enclosed floor, similar considerations will apply to smoke penetration of the enclosures. However, it is probable that smoke will leak through the separations into the floor spaces above or below the floor on fire. The common solution applied to this situation is to place selective controls on the air handling equipment so that in the fire mode the fire floor is placed on extract (to the exterior) and the remainder of the floors are pressurised (Figure 1.4).

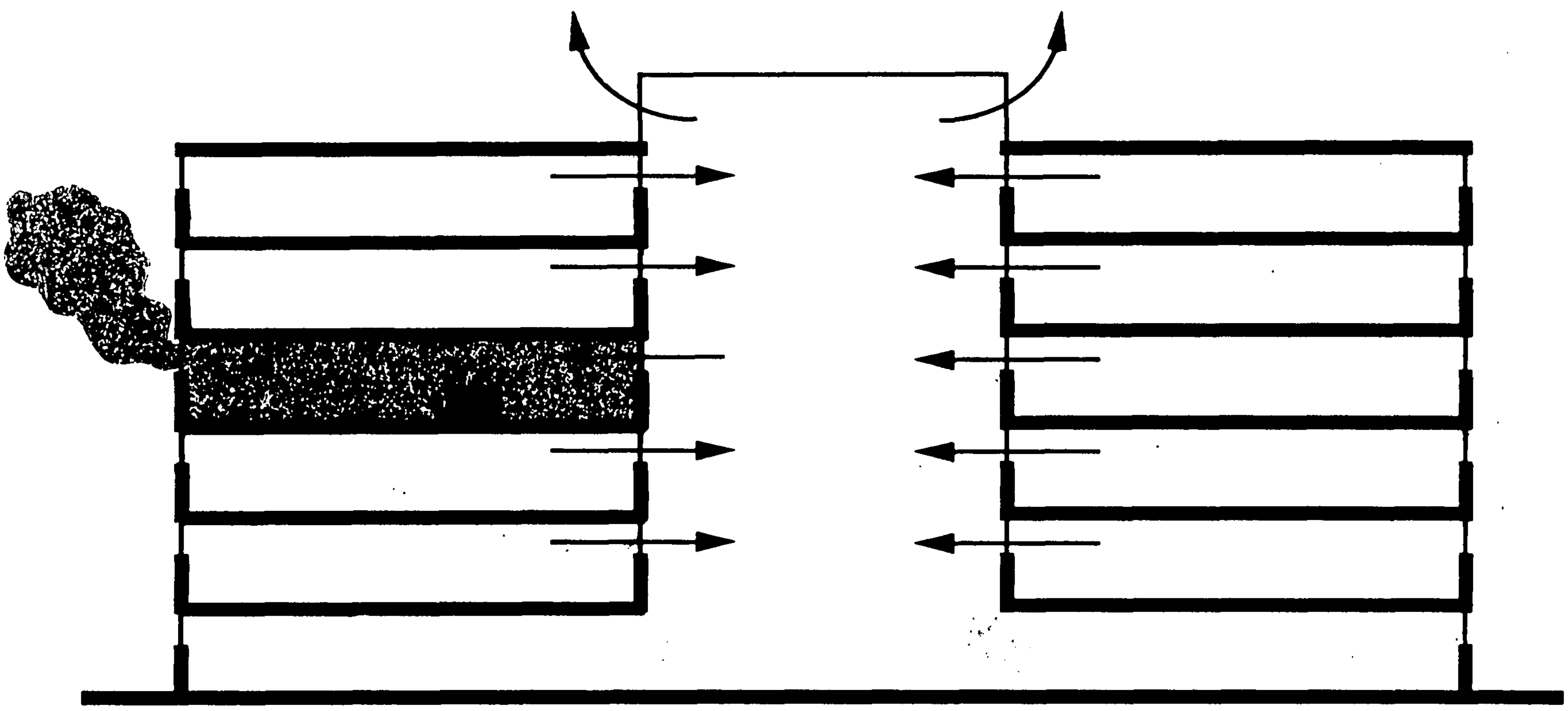


Figure 1.4: Pressurisation of Floors

The "sterile tube" is a name which appears to have been coined from the effect of the Greater London Council rules (GLC 1980) which require the atrium shaft to be separated from adjacent floor spaces by fire-resistant construction, and to contain no fire-risk activities or combustible materials. This approach is said by Ferguson (1985a) to be safe, but extremely cautious. It virtually reverts to conventional compartmentation. There is need to recognise that under these rules, any application to the Council for an atrium building involved a waiver from the London Building Bylaws, and that each project would be subject to negotiations so that these rules only served as a guide in a first approach. Nevertheless they inhibited the full development of the atrium concept in London until some relaxation of their requirements was published in 1985. An inclusion in these 1985 changes was a requirement to use design fires of 1 and 5 MW as a basis for specific smoke control designs.

Where the fire occurs on the atrium floor, there are few measures which will prevent smoke from entering the atrium shaft, since architects and owners commonly require no separation between this floor space and the shaft. Extraction of smoky air from the atrium floor space may not be effective because of the large volume of air that is likely to be involved. Some codes control the amount of combustibles permitted in the atrium floor space, by either limiting it to low risk uses, or, as in GLC, restricting it to pedestrian circulation only. It will be seen later that there are problems in achieving locations for sprinkler heads that ensure effective action to control a fire on the floor of the atrium shaft. Some building owners have adopted 24 hour surveillance of this area but it is questionable whether such controls should be relied upon because they can be circumvented by careless building management practices.

ESCAPE OF OCCUPANTS

From the above consideration of what happens when a fire occurs in an atrium building, it is evident that occupants will be at risk from rapid spread of smoke. Since they may be situated remote from the fire source, it is essential that alarm systems are installed to provide occupants with adequate escape time before smoke reaches them. Where automatic sprinklers are installed, these must be capable of generating an alarm audible to all occupants. It appears from overseas codes that the warning given by a sprinkler system is considered too slow to ensure safe escape by occupants, and so smoke detectors are specified in addition. These are required to be installed so that they will detect smoke in the atrium, and sound alarms in all parts of the building.

Some atrium buildings have stairs and escalators situated within the atrium. This has the attraction of allowing the free flow of people between floors, but in the event of a fire and the atrium becoming smoke-logged, occupants could be trapped while escaping, as will be seen from Figure 1.1. This would become an even more serious problem in say, a department store, where most occupants would be unfamiliar with the layout of exitways. While it is possible to show that the atrium shaft can be kept clear of smoke by ventilation, it is still probable that the upper floors could be affected by smoke and thus put occupants of those floors at risk. It has become popular in the U.S.A. for hotel chains to adopt atrium buildings and to promote these features in their advertising as an incentive to stay at their hotels. These have the bedrooms arranged around the external perimeter, so that the only means of escape is along open balconies located within the atrium shaft. Provided that these balconies lead to a protected stairway, active people may be able to escape along them safely, but disabled people may be disadvantaged in this situation.

There is little doubt that the safest principle to be applied to the philosophy of escape is that people should not have to travel towards a fire or a smoke-logged area in order to reach a place of safety. This principle is evident in NZS 1900.5 where in many situations two or more means of escape must be provided, and this was reaffirmed in DZ4226 where it was proposed that the alternative exitway should have adequate capacity for all the occupants in case fire occurred near to the other one. Applying this principle to atrium buildings points to escape routes leading away from the atrium to protected stairs, as is usual in conventional buildings. Stairs and escalators may be located in the atrium space for everyday use, and in a fire alarm situation people might be expected to use these since they are familiar with them. However, in the event that they find them obscured by smoke, alternatives must be available. Most codes require two separate protected stairways remote from the atrium shaft. UBC permits open escape balconies to be within the shaft but limits the exposed travel distance to the protected stairs to 100 feet (30m).

DESIGN FOR SMOKE CONTROL.

There are different approaches to the design of a ventilation system to control the smoke generated in an atrium fire. Dillon (1987) criticises the situation in the USA concerning the capabilities and efficiencies of ventilation systems designed to control smoke in conventional compartmented buildings. He reports that ASHRAE and NFPA have taken steps to rationalise this situation, but that for the immediate future these do not include solutions to the problems of large, open areas such as atriums and malls.

There are codes where mechanical ventilation systems using air extraction rates in m^3/s or in air changes per hour are required. GLC permits natural ventilation of the atrium shaft only where the building is less than 12m in height, and the vent area must be more than 10 per cent of the atrium floor area. It warns that this extraction rate is intended to reduce the initial spread of fire and smoke, and it is not designed to keep the atrium clear of smoke during all stages of the fire. Above the 12m height, mechanical ventilation is required with a minimum capacity to handle 6 air changes per hour. GLC includes provision for the possibility of designs breaching its quoted general guidelines, provided that the design is a fire-engineered solution specifically applicable to the individual building in question, and each such design will be assessed on its merits.

Several other codes require mechanical systems, and by inference do not permit natural ones. UBC and SBC require not less than four air changes per hour if the enclosed building volume is over 600,000 ft^3 (16,200 m^3), or if less than this volume, six air changes per hour or 40,000 ft^3/min (18.8 m^3/sec). NZFS contains requirements similar to these. NFPA requires an engineered system, but permits the authority to approve an alternative system based on the same air change requirements quoted in UBC and SBC. The basis for these extraction rates is not known, but Butcher (1986) expresses concern that in some situations the solutions resulting from these code rules may be unsafe, because they treat the gases to be handled in a manner traditional to the design of ventilation systems. This ignores the fact that hot gases have considerably more buoyancy than ambient air and occupy a greater volume than when cold.

These problems are recognised by Klote and Fothergill (1983), who exclude the use for atrium buildings of their design manual for smoke control "because there is insufficient test data to ensure the validity of system concepts or of specific calculational procedures for their design". However, the authors recommend that pressurised stairwells and, if possible, zoned smoke control in non-atrium spaces be used in atrium buildings but they do not consider that computer analysis by network modelling methods is appropriate.

Hansell (1986) reports the absence of any detailed fire engineering approach to the design of smoke control systems for atrium buildings. To remedy this, a joint research programme has been undertaken in the UK by H.P. Morgan of the Fire Research Station and G.O. Hansell of Colt International Ltd, who have developed a design approach based on earlier research into fire physics and fire development. In addition, earlier studies of the generation and spread of smoke and hot gas have been applied to various building fire scenarios. Hansell's paper presents the results in a manner which is not too technical, and explains them with copious diagrams.

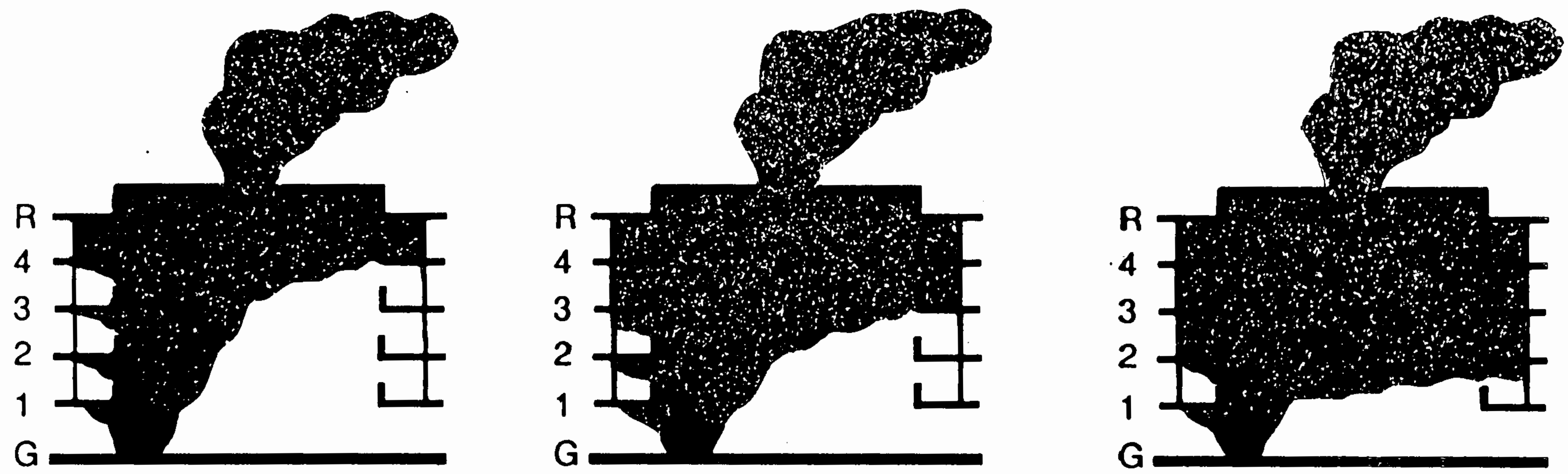
Morgan and Hansell (1987) present methods for predicting smoke flows passing into the atrium shaft from a fire in an adjacent floor space, and for calculating the time for smoke to fill the shaft down to close above the fire. These authors concluded that smoke ventilation systems which require a smoke layer base too high above the fire will fail to keep lower regions free of smoke. This applied both to natural venting and to powered extraction while the fire is burning. Powered extraction will have the advantage of clearing smoke after the fire is out. Morgan and Hansell's paper provides an analysis for use in the design of smoke control systems, but contains too much detail on the derivation of the resulting equations to serve as a guide for a practising engineer in designing a smoke ventilation system for an atrium building. Formulas are provided for calculating the capacity of either mechanical or natural smoke ventilation systems, but the authors acknowledge that their report is not intended as a design guide. It is understood it is their hope that a guide for designers would be prepared as a conclusion to their research. This would certainly fill a need, but at the time of writing, little progress has been made with it. Currently, practising designers can obtain guidance on suitable calculation methods from their paper, and from Hansell (1986), and Butcher and Parnell (1979).

SIZE OF DESIGN FIRE

U.K. design methods adopt an assumption on the size of the fire as a starting point. It has been common to use a maximum design fire area of 3 x 3m. This relates to the size of fire assumed to be possible if sprinklers are installed, since 3m is said to be the required spacing of sprinkler heads in the UK. Without sprinklers, the initial fire is likely to grow beyond this size, with a considerably increased quantity of smoke generated. It could be argued that the larger fire size possible without sprinklers simply means greater quantities of smoke which could be coped with by the installation of a larger extraction system. However this seems to be an unsafe solution and one that appears not to have been acceptable to any of the major code writing groups, since all codes require the installation of sprinklers. Furthermore, such a solution is likely to demand far greater fan capacity and would therefore cost well beyond the needs of normal ventilation functions.

Recently, in the UK, the choice of fire size has been the subject of debate, e.g., Law (1986b). It has been the practice for some years to use a figure of 5 MW for the heat flux evolved and originating from an area of 3 x 3m. As a result of criticism, Butcher (1987) has stated that this figure is only applicable to retail premises, where it is recognised there can be quantities of highly inflammable display material. The 5 MW figure originated from an assumption that the heat output of a fire is approximately 0.5 MW per m^2, and it is now clear that this is too high for offices and hotels. The UK Fire Research Station has never recommended the 3 x 3m size for general adoption as a universal design fire. All other occupancies have always required individual assessment of suitable design fire sizes by agreement with the relevant approving authority for each building. Morgan & Hansell (1985), and Hansell & Morgan (1985) discuss the choice of fire size for those occupancy types in which atriums are more commonly found.

Butcher (1987) makes the important point that fire size is not a constant. Fires start small, and grow with time, and he shows that the 5 MW level may only be reached after 16 - 22 minutes. The critical time for escape is much shorter (most codes are based on 2.5 minutes escape time in paths of travel open to smoke contamination), and it would be better to consider situations at much shorter times from the start of the fire. Parnell and Butcher (1984) examine the effect of a very small fire (1 x 1m size with a heat output of 0.5 MW), which grows to a small fire (1.5 x 1.5m and 1.25 MW), which in turn grows to the usual design fire size (5 MW). Two mechanical extraction rates were applied with these factors to a hotel building where the escape routes are via open balconies within the atrium. The results are illustrated in Figures 1.5 & 1.6 (which are based on Parnell and Butcher, Figures 4 and 5) and it will be noted that in the largest design fire situation almost the whole of the atrium is smoke-logged after about 3 minutes, that doubling the extraction rate achieves only a marginal improvement in this, and that the very small fire still puts people at risk in the escape balconies after about 1.5 minutes. There appear to be difficulties in applying the idea of a growing fire to the determination of likely escape times, since fire growth curves are not available for all occupancies, and the use of a "universal" curve would be unwise. However these calculations emphasise the concerns expressed in Butcher (1986) about the possible dangers to occupants in atrium designs where escape routes are located within the atrium shaft, and emphasises that it is important to consider the impact of a small fire on life safety, as well as a large one.

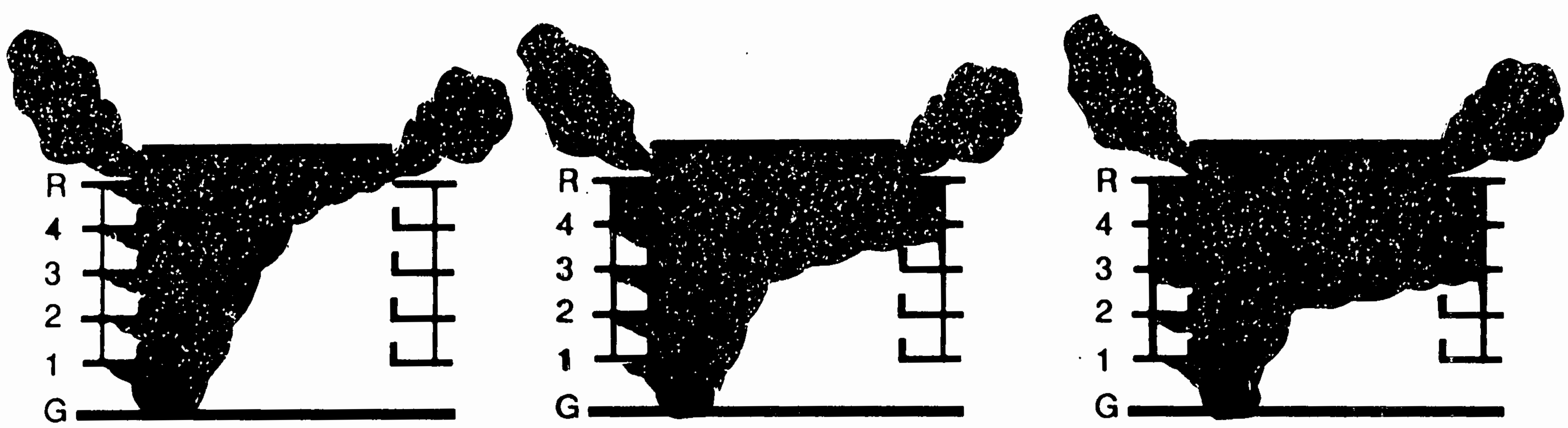


Initial fire 0.5 MW
Smoke at 85 secs

Fire grown to 1.25 MW
Smoke at 150 secs

Fire grown to 5.0 MW
Smoke at 200 secs

Figure 1.5 : Mechanical Extraction at 25m^3/s



Initial fire 0.5 MW
Smoke at 80 secs

Fire grown to 1.25 MW
Smoke at 105 secs

Fire grown to 5.0 MW
Smoke at 190 secs

Figure 1.6 : Mechanical Extraction at 50m^3/s

Hansell (1986) discusses the area, not the heat output of the fire. Fire sizes suggested for the following occupancies are:

sprinklered shops	- 10m^2 area,	12m perimeter	
" offices	- 16m^2 "	14m	"
unsprinklered "	- 47m^2 "	24m	"
hotel bedrooms	- the area of the bedroom floor		

Morgan and Hansell (1987) attempted to relate these fire areas to heat flows. From this they tried to set out a generalised method covering those buildings which may not be provided with sprinklers, and to spell out the consequences in terms of smoke and flame movements. They were not recommending that sprinklers be omitted.

Only GLC and BCA have specific requirements on fire size, related to their call for engineering design of smoke-handling systems.

AUTOMATIC SPRINKLERS

All overseas building codes require sprinklers in atrium buildings. It is evident from several references that the object of this is to control the developing fire. This will have the effect of keeping it small, and thus keeping the quantity of smoke generated to a level manageable by the extraction systems provided. The choice of hazard level for the sprinkler system will depend on the nature of the occupancy use, and in the uses where atriums are most commonly found, a system designed for a light hazard would appear to provide adequate protection. Recent developments in sprinkler technology indicate that "quick response" heads will have an application in atrium buildings.

All spaces which could contain fire load should be covered by sprinkler heads, except that they should not be installed at the top of the atrium shaft. Reasons advanced for this are that there would be a delay in response time while the hot gases rose and accumulated at the heads, and a further delay for the water spray to descend to the atrium floor level. Furthermore, the falling spray may cool the rising gases and render them less buoyant. Butcher and Parnell (1979) suggest that this reduction of buoyancy requires a 20-25 per cent increase in vent area with natural venting. On the other hand, cooling of the smoke before it enters the fans is suggested as an advantage, and that there would be no need to increase the vent area.

There seems to be no completely satisfactory solution to the location of heads to cover combustibles at the atrium floor level. If they were located around its perimeter at the floor level immediately above the atrium floor, they are likely to be effective only against a fire occurring below them. They could be placed in an array suspended no more than two levels above it, so as to cover the whole floor area. Neither method is potentially effective because a sprinkler head needs to intercept a rising fire plume in its inner regions (i.e., near its axis) where gases are hotter than in the outer regions of the plume, and the probability of a small fire occurring immediately beneath a head is low. A solution to this would be to give each area of potential fire load on the atrium floor its own "roof" with its own heads, creating in effect a number of small "buildings" within the atrium space. Another option appears to be 24 hour surveillance of the atrium floor, which is probably

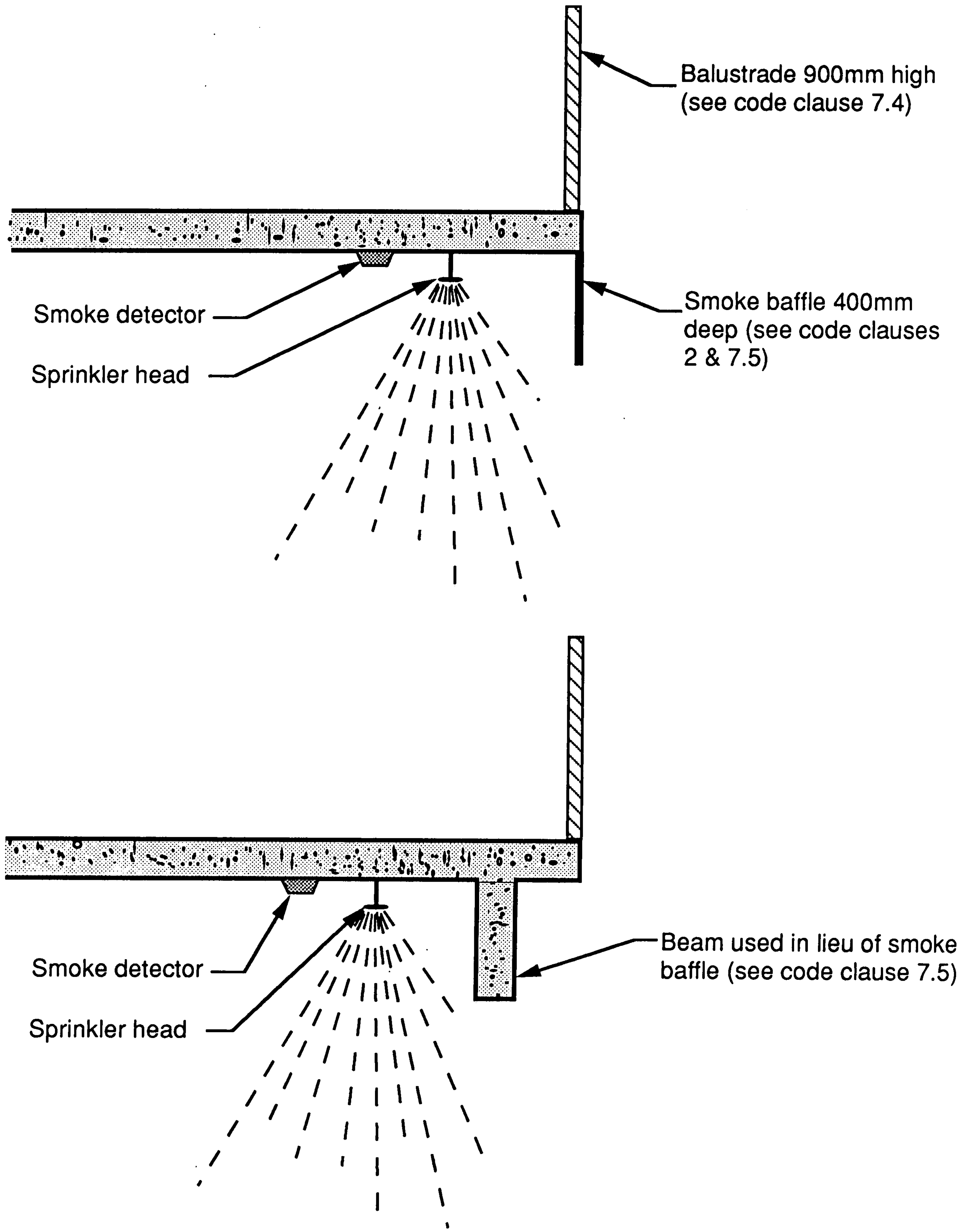


Figure 1.7 : Detail of Floor Edge at Atrium Shaft

satisfactory only where there are other reasons for it, e.g., where the floor is used as a hotel lobby. These are some of the solutions that appear to have been used in overseas atrium buildings.

In the discussion on design fire size, reference is made to a size of 3 x 3m which is related to UK sprinkler spacings. Use of this figure in New Zealand would need to be reviewed since NZS 4541 Automatic Fire Sprinkler Systems requires 4.6m spacing and $21m^2$ area for extra light hazard, or 4.0m and $12m^2$ for ordinary hazard. Adoption of such spacings would result in the attainment of a larger fire before control is established, with consequently a greater volume of smoke to be handled.

Wherever a floor is open to the atrium shaft, even if it is only an interior balcony, there is a danger of slow response of sprinkler heads because of the time it may take to accumulate enough hot gas around the heads to actuate them. It has been suggested that "smoke baffles" (see Figure 1.7) should be installed below the edge of floors to trap smoke and immerse the heads so that these will actuate sooner than otherwise. However smoke baffles may in some circumstances encourage lateral spread of smoke before it rises up the atrium shaft, which is likely to increase entrainment and shorten fill times for the atrium. Perhaps the use of smoke baffles should be limited to where upper floors protrude into the atrium shaft, e.g., at unenclosed balconies and floors open to the atrium shaft.

FEATURES OF VENTILATION SYSTEMS

It is essential that a smoke reservoir be created at the top of the shaft, otherwise as soon as the smoke reaches the top of the shaft, it will begin to spread sideways into the uppermost floor space. This reservoir should be of the order of one storey in height, and be located with its base at roof level of the top floor. This is usually not difficult to achieve within the lantern shape often used, and the buoyancy of this depth of hot smoke will aid its extraction. Some codes, including GLC, UBCM, NZFS, and DZ4226 require a reservoir at the top of the atrium shaft, and others are not specific.

The effect of wind flow over the top of the atrium shaft needs to be taken into account in smoke control calculations. Wind pressure may aid the extraction of smoke, in which case ignoring it will be on the safe side, but if the roof geometry or surrounding landscape/cityscape is such that wind effects oppose the escape of smoke, the extraction system will be less effective. For this reason, it has been suggested that the calculated vent or fan size should be divided equally between leeward and windward sides of the smoke reservoir. However, an option increasingly used in the UK is to install the calculated vent area on either side, with a wind direction sensor to ensure that only the downwind vents open.

No smoke extraction system at the top of the shaft will perform as designed unless adequate quantities of fresh inlet air are supplied. Most codes contain requirements for ensuring that supplies of fresh air are available in the fire mode at the base of the atrium shaft. It is recommended that the quantity should be equal to or greater than the design smoke extraction rate, and it should be made available at the level of the atrium floor. The usual UK approach is to use natural inlets at the bottom with powered exhaust at the top, with some restrictions on the maximum acceptable airspeed through any escape doors that may double as air inlets.

With a fully mechanical system, designers should take care in locating the outlets from fresh air fans, since if an upward jet impinges on the base of a buoyant smoke layer, the resulting mixing could cause such a disturbance of the smoke layer as to lead to downward mixing and poorer visibility at low level.

Where a mechanical exhaust system is used, it has been suggested that fans be part of the normal ventilation system of the building, rather than be installed only for smoke extraction. If this is so, the fans and their controls will be used and maintained regularly and hence will operate when needed in the fire mode. However, in some circumstances smoke extraction can require fan capacities up to an order of magnitude larger than for normal ventilation, and dual-use fans may not always be practical. In these circumstances other measures will be needed to ensure reliable operation. All the fan components should be made of materials capable of operating at high temperatures for a sufficient period to ensure smoke removal can continue until well after the fire has been brought under control.

Any smoke removal system will operate successfully only if it is actuated promptly when a fire occurs. Because detection of smoke will provide earlier response than detection of heat, obscuration smoke detectors should be installed in the atrium. These should scan across the shaft near the lowest level, and at intervals above of no more than three floors. Signals from detectors should be used to actuate alarms throughout the building, and to activate the smoke ventilation systems (including vents, fans and fresh air supply). If balconies within the atrium shaft are used as the only access to floors, then smoke detectors should be spaced at intervals along each level, rather than scanning across the shaft. Smoke baffles dropped below each floor edge will ensure early response, as for sprinklers. In order to reduce the incidence of false alarms, it would seem sensible to have the first detector to sound the alarm, and the second detector to activate the ventilation system, as required by SBC.

ATRIUM SHAFT LININGS

Most codes require the atrium shaft to be separated from adjoining spaces by fire-resisting construction, except that some permit up to three storeys to be open. Where separation is required, the designer is faced with deciding what materials to use. It seems unlikely that solid construction would be used throughout, when the whole point of an atrium is to achieve a sense of openness. For safety reasons, a mixture of solid construction and glazing may be preferred, or for complete visibility a fully glazed wall may be needed. The provision of fire resistance in solid construction presents no more of a problem than in a conventional building, but the provision of fire-resisting glazing requires more attention. There are proprietary glazing systems available with fire resistance ratings proven by test. These systems can be expected to perform their intended function provided that the approved construction details are followed closely, and it is recognised that there will be limitations set by the test on the size of panes that may be used.

Some building codes (e.g., NFPA) specify that glazing may be used to separate the floors from the atrium shaft, but that it must be protected by drenchers. Opinions vary on the value of drenchers. There is the possibility that all or most heads would actuate simultaneously if located in the atrium shaft, causing concerns about adequate water supply, and disposal of the water.

To examine whether this is an effective method of retaining a barrier to heat and smoke, tests have been carried out on glazing which has been wetted on the heated side. Moulen and Grubits (1983) show that if the face of the glass develops dry areas during wetting, the resulting build-up of thermal stresses will cause tempered glass to shatter, and that this can be avoided if the sprinkler spray completely wets the glass. Beason (1986) found that tempered glass performs adequately in a fire large enough to set off the sprinkler heads before the thermal stresses develop in the glass, but that if the glass is located close to a small fire it may shatter before there is enough heat build-up to set off the sprinklers. Beason found that laminated safety glass remains in place even if cracked, and that the cracks are not sufficient to permit penetration of hot gases. Porter and Barnfield (1987) report investigations into the effectiveness of drenchers in maintaining the integrity of glazed enclosures. The tests conducted were designed to simulate the situation where a fire has broken out from one floor level, and the enclosure is required to prevent fire re-entering at a higher level. The results show that where large (2.0m wide x 1.5m high) areas of glass which are not fire resistant are installed, drenchers can ensure a substantial level of protection to the glazing (provided complete water coverage on each sheet of glass is achieved). Richardson and Oleszkiewicz (1987) also found sprinklers effective in protecting glazing for periods up to 2 hours.

Saxon (1983) suggests that where the glazing is placed at the extreme edge of the floor opening, drenchers should be placed on the inside only. However, if glass is heated on one side and kept cool by water on the other, the temperature differential set up may cause early failure. This suggests that drenchers on the inside only might be effective against a fire on the floor remote from the atrium shaft, but it is unlikely that they would be effective against the impact of hot gases within the shaft. Where the glazing is located behind a balcony, Saxon recommends drenchers on both sides. Use of this solution will depend on the individual circumstances of each building.

Every detail of each glazing assembly will need detailed examination to be sure that it will provide a sufficient degree of smoke tightness. It is difficult to specify performance criteria to measure this, since only slow progress has been made internationally on the development of smoke leakage test methods for fire conditions. However, any construction that is draught-tight while serving its normal purpose would appear to meet the need if used in conjunction with the air-handling controls discussed above. The gaskets or beading holding the glass in place must permit freedom of movement, otherwise the glass may shatter when it or the frames distort during heating. Clearly, windows must not open into the atrium shaft.

Some codes specify that opposite sides of an atrium shaft must be at least 6m apart. This appears to be a protection against transmission of heat by radiation from a fire on one side to combustible materials on the other side.

TESTING OF SMOKE-REMOVAL SYSTEMS

Any system intended for removal of smoke generated during a building fire will need to be tested on installation. The owner will need to be satisfied that it has been installed as intended in the contract, and the approving authority will need assurance that it operates effectively, since such a system is part of the safety provisions for the building.

If the system includes mechanical extraction, basic checks will be needed to ensure that all components operate correctly. Pressure and velocity tests should be performed under all expected modes of operation and this represents no more than would be normally carried out during commissioning of a ventilation system. However, if a complicated building geometry is involved, such as could apply in an atrium building, or if untried smoke-control systems are used, it is possible that potential paths for smoke movement may be missed in pressure and velocity tests. In such cases, further tests would be needed. A useful guide on suitable test procedures is given by Klote (1987).

The introduction of smoke into the tests would appear to be an obvious step. The most realistic way to do this would be to set a real fire in a critical location and to observe smoke flows and leakage. However, apart from the obvious risks involved, the likely cost of cleaning up smoky deposits hardly make this a practical solution. The other option is to inject chemical smoke (from a smoke generator or "smoke bomb") into air streams at strategic points during pressure and velocity tests. Klote and Fothergill (1983) point out that such "smoke" is cold and in no way can it be regarded as a means of simulating the buoyancy characteristics of hot smoke, and others have voiced similar doubts on the value of cold smoke tests. Use of tracer gases instead of smoke is another option mentioned, but it is not recommended for similar reasons and also because of the complications of handling and measuring methods necessary. Notwithstanding, some US codes require smoke tests, and undoubtedly many atrium buildings constructed to these codes have been accepted on the basis of apparently successful smoke tests. Recently, in Australia, methods have been developed of effectively generating hot smoke. Enquiries from other sources overseas have revealed little further information.

SUMMARY

In buildings overseas, atriums have become features which are found to be attractive to architects and owners. Some atrium buildings have been constructed in New Zealand, and undoubtedly there will be more. There is an understandable concern about the safety of occupants in the event of a fire, and this is recognised in overseas codes and regulations. Smoke spread has been identified as the major concern and calculation methods are available for the design of smoke-extract systems. There have been few reports of life safety problems in actual fires in atrium buildings, so as yet there is no real proof either that buildings complying with these codes are safe, or that the restrictions contained in these codes are unnecessary. The application of smoke-spread calculation methods is preferable to the use of some code rules, but the mechanisms of the spread of hot smoke are not yet widely understood and so there is a need for designers to become familiar with the application of these methods to the design of atrium buildings.

CONCLUSIONS

1. An atrium is an acceptable way of creating a pleasant internal environment in a building, particularly in a hostile climate.

2. To cater for the possibility of a fire in an atrium building there is a need to pay added attention to life safety over that which would apply to a normal compartmented building.

3. The first consideration in the design of a building containing an atrium must be the provision of adequate means of escape to a place of safety.

4. Mechanical smoke-extraction systems are essential in all but very low atrium buildings.

5. The installation of automatic sprinklers is an essential means of controlling fire growth in an atrium building to ensure that the quantity of smoke generated in a fire is kept to a magnitude capable of being handled by the smoke-extraction system.

6. Calculations for the design of the smoke-extraction system for an atrium building should take into account the behaviour of hot buoyant gases, and such calculations are preferred to code rules which specify fan capacity or air change rates.

7. Smoke detectors are essential in an atrium building for providing adequate early warning of the presence of smoke and for activating the smoke-extraction system.

8. NZS 1900 Chapter 5:1988 lacks requirements governing fire safety design of atrium buildings. In answer to this lack, recommendations for code requirements suitable for New Zealand conditions are included in Part 2 of this Study Report.

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PART 2

CONTENTS

FIRE SAFETY DESIGN OF ATRIUM BUILDINGS: RECOMMENDED CODE OF PRACTICE

PART 2

FIRE SAFETY DESIGN OF ATRIUM BUILDINGS

RECOMMENDED CODE OF PRACTICE

1. APPLICATION

These requirements shall:

(a) apply to any building containing an atrium that interconnects more than two floors, except that some requirements may be omitted in certain small buildings, and

(b) be additional to requirements of NZS 1900.5, and in case of conflict, NZS 1900.5 requirements shall take precedence.

2. DEFINITIONS

The following definitions applying to these requirements are specific to atrium buildings (see Figure 2.1).

Atrium

A (vertical) space (large shaft) within a building interconnecting more than two floors and which is enclosed at the top by a floor or a roof, but excluding an enclosed small shaft used solely for stairs, escalators, lifts or services.

A limited area atrium building means a building with limits of size and occupancy group as detailed in Clauses 3 and 4.

Commentary: Atrium buildings with two floors, except in limited area atrium buildings, are excluded from this code because they present different life safety and smoke handling problems from those with more than two floors (for further background see Part 1 of this report).

Atrium shaft

The space in an atrium bounded by the perimeter of the openings in the floors, or by the perimeter of the floors and external walls.

Commentary: Where floor edges adjacent to the atrium shaft are used for access, the bounding construction need not be at the edge of the atrium shaft.

Atrium floor

The lowest floor level of the atrium.

Commentary: This is often of greater plan area than contained by the atrium shaft, so can consist of an area at the bottom of the atrium shaft, and a perimeter area beyond this, usually underneath floors above.

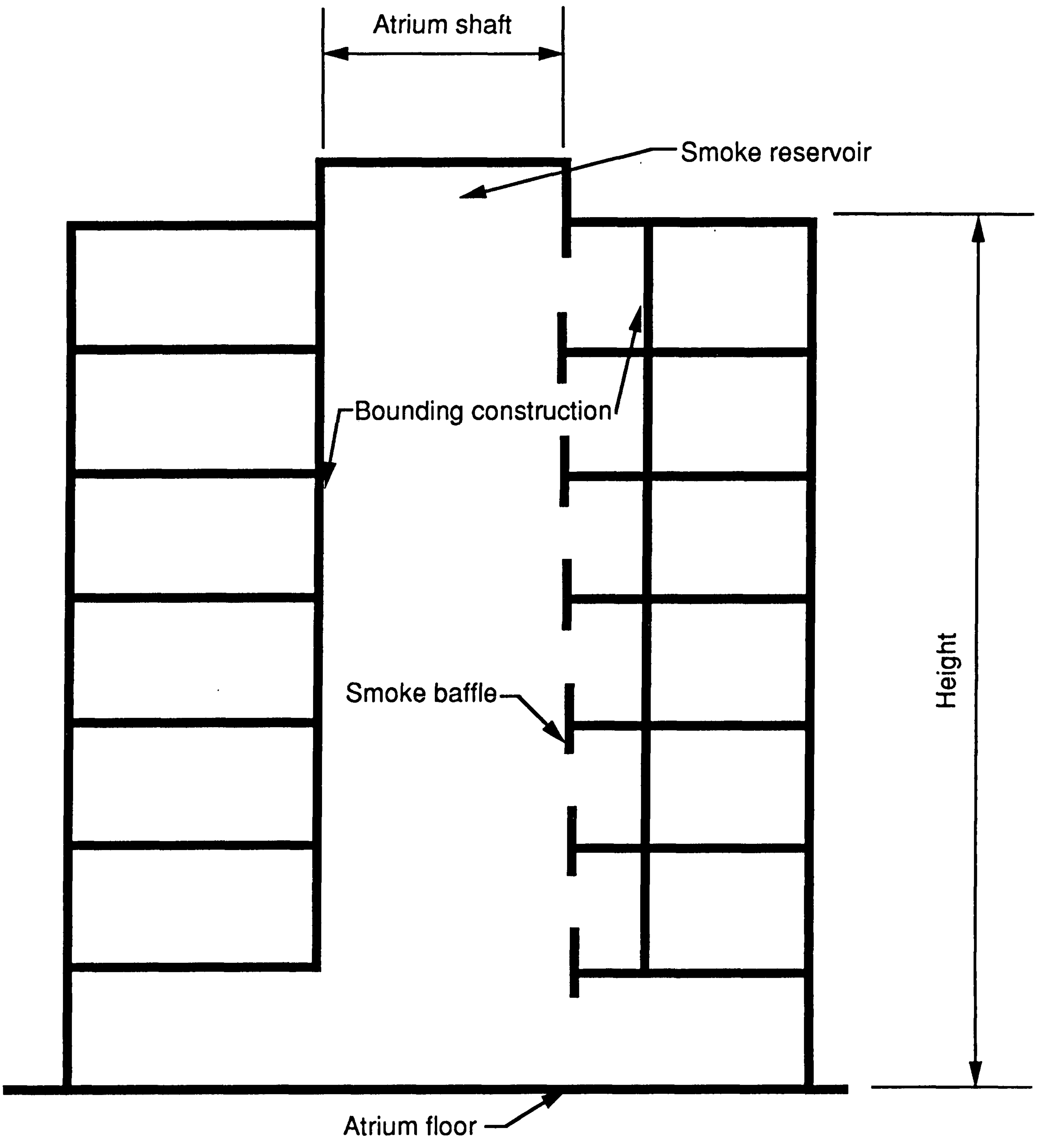

Figure 2.1 : Definitions

Height

For the purposes of this code, the height of an atrium shall be measured from the lowest point of the atrium floor to the underside of the ceiling of the highest occupiable floor.

Commentary: This differs from the definition in Chapter 5 (which measures it to the floor level of the highest floor) and was chosen to emphasise importance of the total volume of the atrium shaft in smoke extraction calculations.

Smoke baffle

A non-combustible fixed baffle attached to the underside of the outer edge of a floor where it protrudes beyond bounding construction, and extending below the ceiling line, or the underside of the floor where no ceiling exists.

Commentary: This is to create a reservoir for trapping hot smoke around smoke detectors and sprinkler heads, and is regarded as essential for ensuring early detection of the presence of smoke or heat. If a ceiling is perforated so that smoke can pass into the space above, and so that penetration of the ceiling by water spray from sprinkler heads located above the ceiling is not impeded, then the ceiling may be taken as non-existent for the purposes of this definition.

3. LIMITED AREA ATRIUM BUILDINGS

A limited area atrium building is a building in which:

(a) the total number of floors does not exceed three (including the atrium floor), and

(b) the total area of all floors does not exceed:

- (i) $400m^2$ with one protected means of egress leading from upper floors; or
- (ii) $750m^2$ with two protected means of egress leading from upper floors; and

(c) the occupant density does not exceed 75 unless the Engineer is satisfied that additional measures have been taken to maintain life safety levels; and

(d) the height measured from the lowest point of the atrium floor to the mean level of the atrium roof membrane does not exceed 13m; and

(e) the upper floors may be open to the atrium shaft.

Commentary: There is a demand for small buildings to house, for example, a group of small offices or professional rooms (say about 15 - $20m^2$ each) with only a small number of occupants (say 50 - 60 people), and where the use of an atrium would increase the appeal of the building. It will be seen in subsequent clauses that in these limited area atrium buildings, sprinklers, mechanical smoke extraction and fresh-air supply systems, and emergency power supply may be omitted, but not smoke alarms. There may be circumstances where it could be safe to permit more than 75 people, say on the ground floor only, and it is left to the Engineer to assess the risks in these cases.

4. PERMITTED OCCUPANCIES

Atriums are permitted in a building containing any occupancy covered by NZS 1900.5 Clause 5.6, but excluding:

(a) group A where the height exceeds three floors; and

(b) groups B1, B2 and D3; and

(c) group D2, except where special features, compensating for the life safety risk of a D2 occupancy, are incorporated to the satisfaction of the Engineer, and subject to there being no D2 activity permitted on the atrium floor within the area covered by the bottom of the atrium shaft.

Limited area atrium buildings shall be restricted to a D1 occupancy group only, except that a D2 occupancy group may be permitted where two separated protected means of egress are provided, and subject to the same restriction on D2 activity on the atrium floor as in (c).

Commentary: The occupancy groups excluded are regarded as having too high a potential for smoke generation in relation to the ability of occupants to escape, notwithstanding the size of the building or the assumption that sprinklers will control the size of a fire. The special features permitting D2 occupancy might include separating the D2 activity with fire-resisting construction or glazed walls protected by drenchers. Where residential occupancies are contained in upper floors located above D2 occupancies, the latter would not need to be fire-separated provided the residential floors have means of egress that do not pass through the atrium shaft at any point.

5. AUTOMATIC SPRINKLERS

An approved automatic fire sprinkler system shall be installed throughout a building containing an atrium, except that sprinklers may be omitted from:

(a) limited area atrium buildings; or

(b) buildings where the height of the building does not exceed three floors and the means of egress from all floors is separated from the atrium shaft by fire-resisting construction complying with the requirements of NZS 1900.5.

Automatic sprinkler systems complying with NZS 4541 shall be approved as meeting the requirements of this code, provided that:

(a) the minimum design density of discharge of the sprinkler and water supply shall have regard to the degree of hazard for the occupancy risk as defined in Table 2.1 of NZS 4541, and

(b) in addition, sprinkler heads shall be located behind the required smoke baffles over the full length of the perimeter of the atrium shaft; and

(c) where the height of the atrium shaft exceeds 13m, sprinkler heads intended for covering the atrium floor at the bottom of the shaft shall not be installed at the atrium roof, but shall be located not more than two levels above the atrium floor.

Commentary: The whole approach of this code to buildings containing an atrium is based on the requirement that the building is sprinklered throughout, with an exception for limited area atrium buildings. By this means it is expected that the growth of a fire will be controlled, and this will reduce the volume of smoke produced. At the same time the code also includes mandatory requirements for smoke alarms which it is believed go hand in hand with sprinklers to achieve the aim of ensuring adequate life safety for occupants.

There are practical problems in ensuring adequate coverage of combustibles located on the atrium floor at the bottom of the atrium shaft. Placing sprinkler heads at the top of a tall shaft suffers from the disadvantage of slow response to a fire commencing well below them, and water falling down through rising smoke may cool the smoke with consequent loss of buoyancy. Placing the heads at a lower level is not totally satisfactory unless each head is covered by a canopy or hood which will trap enough hot gas to activate the head. Placing heads with long throw potential at the perimeter of the shaft may not be entirely effective, since they may not be located favourably to intercept a rising plume of hot gas. The approving authority will have to consider each case on the circumstances and may need to accept special measures (e.g., hose reels) installed to deal with this specific hazard.

6. MEANS OF EGRESS

Except in limited area atrium buildings as provided for by (g) below, a minimum of two means of egress shall be provided from all points within the atrium and from adjacent floor spaces not separated from the atrium shaft, and entry points on each level into these means of egress shall be remote from each other, provided that:

(a) all means of egress from upper floor levels above the atrium floor shall be protected as required by NZS 1900.5; and

(b) each floor level shall have a protected means of egress except where complying with the requirements of Clause 5.35 Mezzanine Floors of NZS 1900.5; and

(c) exits are indicated by signs and directional arrows in predominantly Safety Green in general compliance with NZS 5807 and NZS 1900.5; and

(d) the total capacity of all exits is calculated according to Clause 5.32 of NZS 1900.5 subject to it being sufficient to permit the simultaneous escape of all occupants of all levels not separated from the atrium shaft; and subject to the individual capacity of each exit being not less than 50 per cent of the total where two alternative exits are provided; 35 per cent where three are provided; and to the approval of the Engineer where more than three are provided; and

(e) exitways from each floor not fire separated from the atrium shaft shall lead away from the shaft, and the individual capacity of each exitway shall be as required in (d); but

(f) where balconies open to the atrium shaft are used as access to occupiable space which is not provided with alternative exits remote from the atrium, the length of unprotected routes of travel shall not exceed 30m, or 45m if sprinklered; and

(g) in limited area atrium buildings, the length of unprotected routes of travel in (f) shall not exceed 24m, but if this distance does not exceed 18m, the number of required protected exits may be reduced to one.

Commentary: The principle in NZS 1900.5 of requiring adequate number and capacity of exitways is extended in this code to cover where floors may be open to the atrium space and hence liable to rapid smoke-logging. It is recognised that if all occupants on each level have a choice of travelling in two or more directions away from the fire or smoke their ability to escape is considerably enhanced.

In (f) it is not the cul-de-sac situation which is envisaged because two protected ways off the upper floors are required, hence longer distances of travel than required by Clause 5.37 of NZS 1900.5 are considered safe. The increase in unprotected travel distance permitted for sprinklers reflects growing acceptance overseas of sprinklers for life safety purposes (e.g., NFPA 101). In (g) the distance is reduced (to 24m) because open upper floors are permitted and because sprinklers are not required. It is reduced even further (to 18m) because of the cul-de-sac situation associated with one means of egress.

7. ATRIUM SHAFT SEPARATION

7.1 Fire resistance

7.1.1 Floors

All floors in buildings containing atriums shall have FRR as required by NZS 1900.5 for the relevant occupancy groups.

7.1.2 Bounding construction

Except in limited area atrium buildings, the atrium shaft shall be separated from the remainder of the building at each floor by bounding construction that:

(a) comprises a wall that has a fire resistance of not less than 1 hour, and which extends from the floor to the underside of the floor above (if any), or the underside of the roof; and

(b) where fixed glazing is incorporated in the wall required by this clause, the glazing shall be either an approved fire-resisting glazing system, or a glazing system which is not fire-resisting but protected by sprinklers installed on the atrium shaft side so designed and placed that on actuation they drench the whole surface of the glass; but

(c) subject to Clause 9.4.1, up to three floors immediately above the lowest point of the atrium floor need not be separated from the atrium shaft, except that this shall not be permitted where the upper floors contain accomodation used for sleeping.

7.1.3 Adjacent construction

Where the atrium is adjacent to construction extending above the roof penetrated by the atrium shaft and which is part of the same fire compartment, external walls above the roof and within 10m of the atrium roof shall have FRR as required by this clause.

7.2 Openings in bounding construction

A doorway or other opening in construction bounding an atrium shaft shall be protected:

(a) in a wall as required under Clause 7.1.2 (a), by a self-closing one hour fire door complying with the requirements of NZS 4232 Part 1; and

(b) in a wall incorporating glazing as required in Clause 7.1.2 (b), by a self-closing fire door complying with the requirements of NZS 4232 Part 1, or by glazing complying with the requirements of NZS 4232 Part 2.

7.3 Set-back of bounding construction

Except as permitted by Clause 7.1.2 (c), the bounding construction required to separate the atrium shaft from the remainder of the building may be set back from the edge of the atrium shaft by no more than a distance of 3.4m.

7.4 Balconies

Where a balcony is open to the atrium shaft and provides the only means of access to occupiable space on an upper floor, a balustrade shall be attached to the edge of the floor, and shall be not less than 900mm in height above the floor level, and of non-combustible construction capable of resisting penetration of smoke.

7.5 Smoke baffles

Where floor spaces are not separated from the atrium shaft by fire-resisting construction, or where balconies protrude beyond the bounding construction, smoke baffles shall be provided at the edge of all floors over the full length of the perimeter of the atrium shaft. Smoke baffles shall extend vertically a minimum of 400mm below the ceiling line, or below the underside of the floor where no ceiling exists. Down-standing beams of non-combustible construction may be used in lieu of smoke baffles.

7.6 Separation of plant rooms and equipment

A space containing a transformer, generator, boiler, etc, or the main electrical switchboard for the building, opening on to space which is part of the atrium volume, shall be enclosed by walls with FRR complying with the requirements of NZS 1900.5 and the Dangerous Goods Act, 1974.

7.7 Smoke Reservoir

Where the top floor is not separated from the atrium shaft by fire-resisting construction as required by Clause 7.1.2 (a) or (b), a smoke reservoir shall be created by raising the roof membrane of the atrium shaft above the main roof line by a height equivalent to the height of that floor, or in such a way as to provide an equivalent volume.

Where the top floor is fire-separated from the atrium shaft, a reservoir shall be created with sufficient height to accomodate the smoke vents required in Clauses 9 and 10, but in no case shall this height be less than 2m.

In limited area atrium buildings the mean level of the atrium roof membrane shall be not less than 5m above the topmost floor, unless the Engineer is satisfied that alternative special measures have been taken.

Commentary: It is essential that there is a smoke reservoir at the top of the atrium shaft to ensure adequate smoke extraction. The height of 5 m above the topmost floor in a limited area atrium building is to create an adequate smoke reservoir.

8. DIMENSIONS OF ATRIUM SHAFT

Where occupiable space in a floor faces across an atrium shaft to other occupiable space, the shaft shall have a minimum width of 6m measured horizontally from the perimeter of the shaft at any point, except that escalators, lifts or stairs, situated within the atrium shaft, need not be included for purposes of this clause. Where there is no occupiable space across an atrium, this minimum distance may be reduced to 4m.

Commentary: This minimum width is intended to avoid fire spread across the shaft by radiation or flame penetration from a fire on an upper floor. It will also improve the characteristics of the atrium shaft to avoid turbulent air flow and hence minimise intermixing of smoke and air. The reduced distance would apply where the atrium is "one-sided", i.e., where occupiable space faces across the shaft to a wall, and this is most likely to apply in a limited area atrium building.

9. SMOKE-CONTROL SYSTEM

9.1 General

A building containing an atrium shall be provided with a smoke control system.

Where the height of the atrium is over 13m or four floors, whichever is the lesser, a mechanical smoke-extraction system complying with AS 1668.1 shall be used except where varied or superseded by this code; but where the height is equal to or less than this, or in a limited area atrium building, a natural-draught smoke-extraction system may be used as an alternative to a mechanical system.

9.2 Operation of mechanical smoke-control system

An atrium mechanical smoke-extraction system shall be capable of operating independently of any other ventilation system in the building, and shall be designed to operate so that if a fire occurs in the atrium or in floors not fire-separated from it, or smoke from a fire outside enters the atrium, it shall:

(a) exhaust smoke from the atrium shaft; and

(b) pressurise all adjoining enclosed spaces in such a manner that smoke will not leak from the atrium shaft; and

(c) protect paths of travel to exits within and from the atrium by containing the smoke with a flow of fresh air into the atrium shaft.

9.3 Controls

An atrium smoke control-system shall be actuated by the operation of any of the following:

(a) the automatic smoke-alarm system;

(b) the automatic sprinkler system;

(c) a manual start switch limited to the specific use of security and Fire Service personnel,

and all controls for the system shall be located adjacent to the Fire Indicator Board or other approved place.

9.4 Smoke Exhaust System

9.4.1 Design of system

A smoke extraction system installed to the requirements of Clause 9.2 shall be designed using calculations taking into account the buoyancy properties of hot smoky gases. The building volume used in these calculations shall include the volume of any unenclosed floor spaces not fire-separated from the shaft in addition to the volume of the shaft.

Calculations shall be based on the following sprinkler controlled design fires:

(a) where an atrium is permitted by Clause 4 in a building containing:

(i) a group A, B3, C1 or D1 occupancy:

1.5 MW with 7m perimeter

(ii) a group D2 occupancy:

5 MW with 12m perimeter; or

(b) such other approved heat output and fire size based on the actual fire load anticipated for the occupancy group for which the building is designed.

Commentary: Refer to Part 1 of this report for possible calculation methods.

9.4.2 Exhaust discharge

Smoke exhausted from the atrium shall be discharged through automatically opening vents, either:

(a) vertically from the highest level of the top of the atrium shaft; or

(b) horizontally, at a height greater than where emergency services may have to operate by at least one full floor height, and where calculations of wind velocity-induced pressure profiles for the building verify that the exhaust system will operate effectively in all wind directions.

9.4.3 Exhaust fans

Where smoke exhaust fans are installed as a requirement of this specification they shall be capable of running at an air/smoke temperature of 300°C for a minimum of one hour, and of running continuously at 40°C. Other, higher, operating temperatures may be used, subject to substantiation by the fan manufacturer.

A minimum of three fans shall be provided, each capable of exhausting 50 per cent of the total required smoke exhaust capacity, and located so as to be distributed on both sides of the atrium reservoir.

9.4.4 Upward air velocity

The average upward air velocity in the atrium shaft due to the operation of the mechanical smoke-extraction system shall not exceed the following maximum velocities:

(i) 3.5 m/s where the occupancy group requires a 1.5 MW design fire size ; or

(ii) 5.0 m/s where the occupancy group requires a 5 MW design fire size.

Commentary: Where access to upper floors is provided by balconies situated in the atrium shaft, it is desirable that the upward velocity be not less than 0.2 m/s unless special provisions are installed to limit the spread of smoke from the shaft into the balconies (e.g., by fresh air curtains).

10. MAKE-UP AIR SUPPLY

10.1 General

A building containing an atrium shall be provided with a make-up fresh air supply system in accordance with this clause, and openable vents shall be installed with automatic activation by the required smoke-detection system; and

(a) where a mechanical smoke-extraction system is required by Clause 9.1, the make-up air supply shall be mechanically operated and automatically activated; but

(b) where a natural extraction system is permitted by Clause 9.1, the make-up air supply may be provided by natural draught.

10.2 Operation

The required make-up air supply system shall:

(a) have a capacity equal to or greater than the smoke extraction system; and

(b) supply fresh air from outside the building:

   (i) at or near the atrium floor; and

   (ii) over the perimeter of the atrium shaft at low velocity; and

(c) maintain a velocity of not less than 0.1 m/s from paths of travel and unenclosed floors (if any) toward the atrium shaft.

10.3 Doors in Escape Routes

The make-up air supply system shall be designed to avoid excessive pressures opposing the opening of escape doors located in the air flow, and excessive air velocities through such doorways when open.

11. MANUAL SMOKE VENTS

An atrium shall be provided with openable vents for releasing smoke to the outside air which shall be capable of manual operation; and

(a) be situated at or near the top of the atrium shaft or smoke reservoir; and

(b) have an aggregate clear opening area of not less than 5 per cent of the average plan area of the atrium shaft; and

(c) have controls located adjacent to the Fire Indicator Board or other approved place, able to override automatic controls where installed.

12. ALERTING DEVICES

The entire building containing an atrium shall be provided with an approved alerting system which shall:

(a) be installed and continuously monitored to a standard not less than required by type C of NZS 4561, supplemented by the standard for alerting devices in NZS 4512; and

(b) be activated by any of the following:

  (i) the automatic sprinkler system

  (ii) the smoke detector system

  (iii) manual call points

  (iv) a central control point, located adjacent to the Fire Indicator Board or other approved place, and for the specific use of security and Fire Service personnel; and

(c) be capable of sounding a predetermined alert signal; and

(d) permit alerting and voice signals to be distinctly heard in every part of the building above any background noise.

Where the height of the atrium is over 19m or six floors, whichever is the lesser, the entire building shall be provided with approved voice-over capability complying with AS 2220 and such that selective or general voice alarms or instructions may be initiated by security or Fire Service personnel. Where there may be occupants with hearing impairments, visual alerting devices shall be installed additionally in all sleeping spaces.

13. AUTOMATIC SMOKE-DETECTION AND ALARM SYSTEM

A building containing an atrium shall be provided with an automatic smoke detection and alarm system complying with NZS 4512, and with the requirements of this clause.

Detectors shall include an approved gating system of automatically verifying the first signal within an elapsed time of not more than 30 seconds.

Detectors shall sample air from within the atrium shaft and in all spaces that are not fire and smoke separated from the shaft, as follows:

(a) point-type detectors shall be located close to the edge of any floor adjacent to the shaft behind smoke baffles or down-standing beams, and placed so as to cover the whole perimeter of the shaft.

(b) beam-type detectors shall be located within the shaft, at the first floor level above the atrium floor and at intervals of not more than three floors, and shall be arranged to scan at 90° to those above or below; except that in limited area atrium buildings, point-type detectors located at least 100mm below the roof membrane at the top of the shaft may be substituted for beam-type detectors within the shaft.

Commentary: There is a concern about the incidence of false alarms from smoke detector systems. Causes include not only system malfunctions, but also genuine activation of the alarms caused by ambient conditions which the detector senses as a smoke condition but which is not. The cost of any activation not only includes the cost of a Fire Service turnout but also the disruption of the activities of the occupants. On the other hand, loss of time in initiating a call to the Fire Service is a common cause of increased losses arising from a delayed arrival. Advances in detector technology now permit systems to be installed which are self monitoring, and have the potential of greatly reducing the incidence of false alarms.

It is an important aim to ensure that any smoke generated by a fire originating either on the atrium floor or on floors not separated from the atrium be detected early. The most effective location for detectors to achieve this aim is around the perimeter of the atrium shaft so as to detect the smoke before it spills over into the shaft. If the fire originates on the atrium floor at the bottom of the shaft, detectors in these locations will not intercept the smoke plume, which can only be detected by beam-type detectors scanning across the shaft. It should be noted there are no exceptions to the requirement for a smoke detection and alarm system even in limited area atrium buildings.

14. ALARM SYSTEMS OPERATION

Alarm and detection systems required by this code shall operate as follows:

14.1 Smoke detection system:

Actuation of any smoke detector shall alert building management that abnormal smoke levels have been detected.

On confirmation of the presence of smoke, the detection system shall automatically:

(a) call the Fire Service; and

(b) activate emergency warning and communications systems; and

(c) open all vents which are part of the smoke extraction and make-up air supply systems; and

(d) start smoke extraction and make-up air supply systems, including stairwell pressurisation (if installed); and

(e) de-activate plant not necessary for fire safety within the building; and

(f) start the emergency power supply (if installed).

14.2 **Automatic sprinklers, manual alarms, or the central control:**

Actuation of any of these systems shall initiate all the actions specified in Clause 14.1.

15. EMERGENCY POWER

In any building containing an atrium with a height of over 19m or six floors, whichever is the lesser, a standby generator set complying with NZS 6104 shall be provided, so that, in a fire emergency, adequate power shall be supplied to:

(a) all components of the smoke control system; and

(b) the emergency lighting system; and

(c) any lifts located in, or opening into the atrium shaft, so that they may be returned to the atrium floor level.

The standby generator set shall be driven by a prime mover provided with an independent dedicated fuel supply.

16. SYSTEM PROTECTION

Where applicable, all components of the smoke control system, including wiring and switching to air-handling plant, essential control and detector circuits and sources of emergency power shall be fire-protected in an approved manner.

17. EMERGENCY LIGHTING

An emergency lighting system complying in all respects with NZS 6742 shall be installed throughout the atrium shaft and any surrounding floor spaces open to the shaft, but may be omitted in limited area atrium buildings.

18. TESTING

18.1 Before occupation

The smoke control system shall be demonstrated to the Approving Authority to show that:

(a) all fans, detection and alerting systems, and emergency power and lighting systems operate in the manner intended; and

(b) the smoke removal capabilities are attainable by conducting tests using heated smoke. Proposed procedures shall be agreed with the Approving Authority prior to the running of the tests. In limited area atrium buildings, smoke tests before occupation may be omitted with the approval of the Engineer.

Commentary: Testing with smoke generated by smoke bombs will check such things as whether fans run with the correct rotation and that air flows are generally in the direction intended. However, cold smoke cannot be expected to simulate the behaviour of hot gases rising up an atrium shaft, and some measures are necessary to heat the smoke to create a plume rising upwards through the shaft. During these tests, exit signs complying with this code should be placed in suitable locations in exitways, and observations made throughout the duration of testing of their continuing visibility at the specified maximum travel distances.

18.2 After occupation

The owner shall ensure that quarterly surveys are carried out on the smoke exhaust system by starting the smoke extraction fans manually to ensure satisfactory running. Surveys shall be done in conjunction with surveys of the operational functions of the fire and smoke alarm systems, and shall be carried out by approved personnel, who shall prepare a report, with copies to be made available to the owner, the approving authority, and the insurers of the building.

Commentary: Much of the life safety protection provided for occupants by this code depends on the automatic response of electrical and mechanical systems. It is therefore important that the systems be periodically checked, and that it can be verified by independent audit that these checks have been carried out.

CODES ETC REFERENCED IN PART 2

NZ LAWS, STATUTES ETC

Dangerous Goods Act, 1974. Government Printer, Wellington.

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NZS 4232: 1988. Code of Practice: Performance Criteria for Fire Resisting Closures. Part 1 Internal and External Fire Doorsets. Part 2 Fire Resisting Glazing Systems.

NZS 4512: 1981. Automatic Fire Alarm Systems in Buildings.

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NZS 4561: 1973. Specification for Manual Fire Alarm Systems for Use in Buildings.

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