Design of Sprinklered Shopping Centre Buildings for Fire Safety

Fire Design Guide 2006

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Design of Sprinklered Shopping Centre Buildings for Fire Safety

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Scope

This publication applies to sprinklered shopping centre buildings having a *rise in storeys* of up to 4. The buildings may contain covered walkways and a combination of the following classes of building (in terms of the BCA):

- *Class 6* — Retail including specialty shops, major stores, department stores, supermarkets
- *Class 9b* — Cinemas
- *Class 7* — Carparks including open deck and sprinklered carparks
- *Class 5* — Offices

The publication applies to buildings which are of substantially non-combustible construction. However, this should not be taken to exclude the use of timber stud wall construction between specialty shops.

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INTRODUCTION

The construction and extension of large shopping centres is an area of commercial development which is being pursued actively in Australia. There is a belief that some aspects of the current *deemed-to-satisfy* provisions for these buildings may be unnecessarily onerous, imposing unnecessary financial burdens on developers and owners and which do not relate to the risk to life from fire in these buildings.

A two-year intensive research project, Fire Code Reform Centre (FCRC) Project 6, was conducted to study all significant aspects relating to fire safety in shopping centres. The purpose of this project was to review the requirements in the Building Code of Australia (BCA) [1] which apply to low-rise sprinklered shopping centres and to propose a more rational set of fire-safety requirements to improve the cost effectiveness of these buildings (both in terms of construction costs and maintenance in operation) whilst maintaining the current high levels of fire safety.

A set of reports [2-8] which describe the various aspect of the research work have been published. The final report [9], also published as an FCRC document, summarises the research and systematically evaluates fire-safety aspects of shopping centre buildings making recommendations for the design of such buildings. Since that time, further evaluation and testing have been conducted and the design principles and procedures given in the above publications have been extended in the light of new information. The design principles and procedures have taken into account the methodologies and fire-safety system structure given in the Fire Engineering Guidelines [10] prepared by FCRC and endorsed by Australian Building Codes Board.

The purpose of this publication is to present this modified design approach. This approach will enable the designer to satisfy the *fire-safety objectives* and relevant *performance requirements* of the BCA. The satisfaction of the performance requirements depends on many factors, including the correct choice of materials of construction, appropriate egress requirements, adequate fire suppression, and appropriate structural fire resistance.

The design is applicable to buildings which contain multiple classes, when considered with respect to the BCA, which may contain a covered walkway or mall and the following classes of buildings:

Class 6 —	Retail including specialty shops, major stores, department stores, supermarkets
Class 9b —	Cinemas
Class 7 —	Carparks including open deck and sprinklered carparks
Class 5 —	Offices

It does not apply to retail "warehouse" buildings where goods are stored in tall racks greater than 4 m in height and where the sprinklers are located only at roof height. This is not to say that the information presented in this publication can not be applied to other situations but that it may be necessary to consider additional matters.

It is recognised that both life safety and property protection are of importance in shopping centre buildings. A large fire in these buildings may not only present a major threat to life and may result in significant direct property losses, but more importantly, an ongoing loss of sales revenue through interruptions and delays to the provision of goods and services. Therefore, life safety and property protection are considered in this publication.

It needs to be stated that it is practically impossible to design modern shopping centres to satisfy all of the *deemed-to-satisfy* provisions of the BCA. Furthermore, the factors which have, by far, the greatest impact on fire safety, are not addressed by attempting to design the building to satisfy the *deemed-to-satisfy* provisions. It follows therefore, that a fire-engineering evaluation of the type presented in this publication, is essential for shopping centre buildings.

BACKGROUND

Research Project

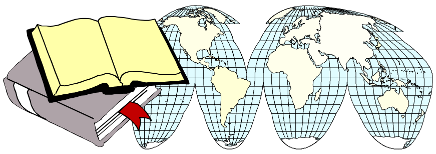
FCRC Project 6 was conducted to study all significant aspects relating to fire safety in shopping centres. Research participants included BHP Research, BCC, Victoria University of Technology and Scientific Services Laboratories.

The project involved various parts, including:

- review of current BCA requirements
- survey of shopping centres
- review of retail fire incidents
- review of retail fire statistics
- identification of key issues
- fire testing
- study of behaviour of building occupants
- study of effectiveness of smoke control systems
- systematic evaluation of fire safety

Some aspects of the project are outlined below.

Case Studies

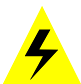


97 accounts of fires in retail and shopping centre buildings, as reported in the literature, have been considered. Ref. [5] documents details of the fatalities experienced in retail buildings in the USA over a 10 year period from 1983 to 1993 (except 1986). The data was obtained from the National Fire Incident Reporting System (NFIRS) in the USA [11].

The analysis of the case studies revealed a number of apparent trends and the following tentative observations can be made:

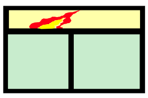
General Observation from Case Studies

- The majority of fires appear to have been started by electrical faults or arson.

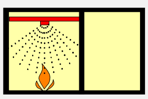


- In the majority of situations fires only developed to a significant size if the fire was initiated in unpopulated areas (eg. storage areas or ceiling spaces) or when the building was unoccupied.

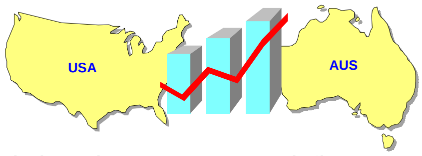
- A major mechanism of fire spread to other parts of the building appears to have been through the ceiling space.



- Partial sprinklering is a dangerous practice which can lead to the centre being effectively destroyed.



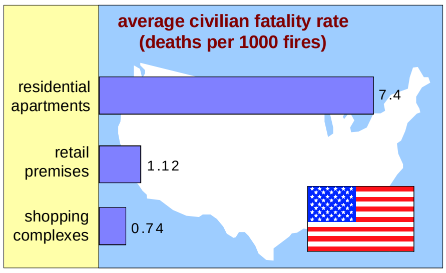
Fire Statistics



The statistical data on USA retail fires attended by the fire brigade were analysed. These data, contained in the NFIRS database, includes 10 years (1983 to 1993 excluding 1986) of data and represents 77,996 retail fires.

For comparison, a further study was carried out on data available from the New South Wales (NSW) Fire Brigades for NSW for the years 1986 to 1992. An analysis of Australian fire statistics for commercial buildings has also been undertaken. A comparison of the data indicates that remarkably similar trends are demonstrated between the USA and Australian data and this confirms that it is reasonable to use the larger USA database for understanding many aspects of fires in retail buildings.

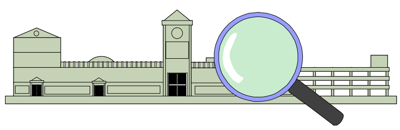
It is clear from the data that fire in retail premises does not present a significant risk to life. There were 86 deaths in 77,996 retail fires over 10 years in the USA and only two fatal fire incidents in NSW. The figure below shows the average fatality rate for civilians (as opposed to fire fighters) obtained from the USA data.



In NSW the comparable figure for retail premises is 0.79 deaths per 1,000 fires, but since this is based on only two fatal fire incidents, the figure must be used with caution. The Australia fatality rate in residential buildings is 7.08 per 1,000 fires

There is a general trend, for the numbers of civilian deaths and injuries to increase with size of the fire. In fact it is shown in the analysis given in [6] that if by some means all fires could be confined to the object first ignited, the civilian fatality rate would probably fall by a factor of nine.

Survey of Shopping Centre



As part of the research project it was considered important to gain an adequate understanding of all aspects of shopping centres that relate to fire safety. This knowledge is essential to permit a meaningful fire-safety analysis.

Information on these matters was gained by means of a very comprehensive study of a major shopping centre in Victoria over a continuous two month period and through visits to eleven shopping centres in Victoria and NSW. The centre subjected to the comprehensive study had a gross retail area of 58,000 m^2 having a department store with a *rise in storeys* of 4 at one end of a two storey mall and was considered to be representative of a large modern shopping centre. The other centres had *rise in storeys* of up to 5, and with one exception, had floor areas which were similar or greater than that associated with the centre used for the detailed study.

For each centre visited, interviews were conducted with operational staff to understand their approach to a variety of matters and to obtain a general overview of practices and construction.

A summary of the findings from these visits and of the data obtained is given in [3].

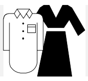
Fire Tests

In designing shopping centres for fire safety, it is essential to have some understanding of the characteristics of fires that may occur in these buildings, and because of the paucity of relevant tests, it was considered essential to conduct a series of fire tests that would provide such data.

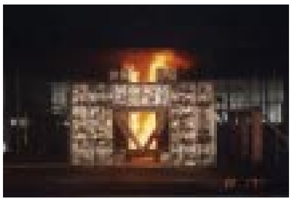
Full-Scale Fire Tests

Eleven full-scale fire tests were conducted to investigate the effects of fires in specialty shops and major stores in a shopping centre.

Fire Test Program

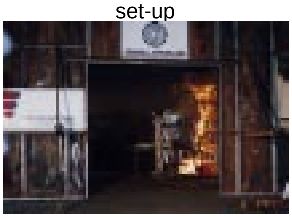
Tests 1 & 2	simulate fires in a toy store under sprinklered and non-sprinklered situations.	
Tests 3 & 4	simulate fires in the storage area of a shoe shop under sprinklered and non-sprinklered situations.	
Tests 5 to 9	simulate fires in clothing stores under sprinklered situation.	
Tests 10 & 11	simulate fires in book shop/ newsagent under sprinklered situation.	

fire test on toy store set-up



fire test on shoe storage area set-up

fire test on clothing store set-up



Fire test on book shop/ newsagent set-up

As a result of these tests, 3 types of fire were identified according to their size:

- ***C1***—fires which are kept small without the presence of sprinklers.
- ***C2***—fires controlled by the presence of sprinklers.
- ***C3***—fires which are significantly more severe than C1 and C2.

The results of the tests are reported in detail in [7] and a videotape is available.

Model Fire Tests

Model Tests can be used to enable a better understanding of aspects of smoke movement in shopping centres. Such testing has been carried out in the past by others to develop a basis for various numerical correlations. A set of model tests is being conducted at Victoria University of Technology using the model four-storey building shown below. The model is 1/7 scale and is designed such that horizontal openings can be incorporated in the floors and the roof. This model has been used to study the flow of smoke through floor openings and the effects of roof vents on the amount of smoke in each level.

model four-storey building

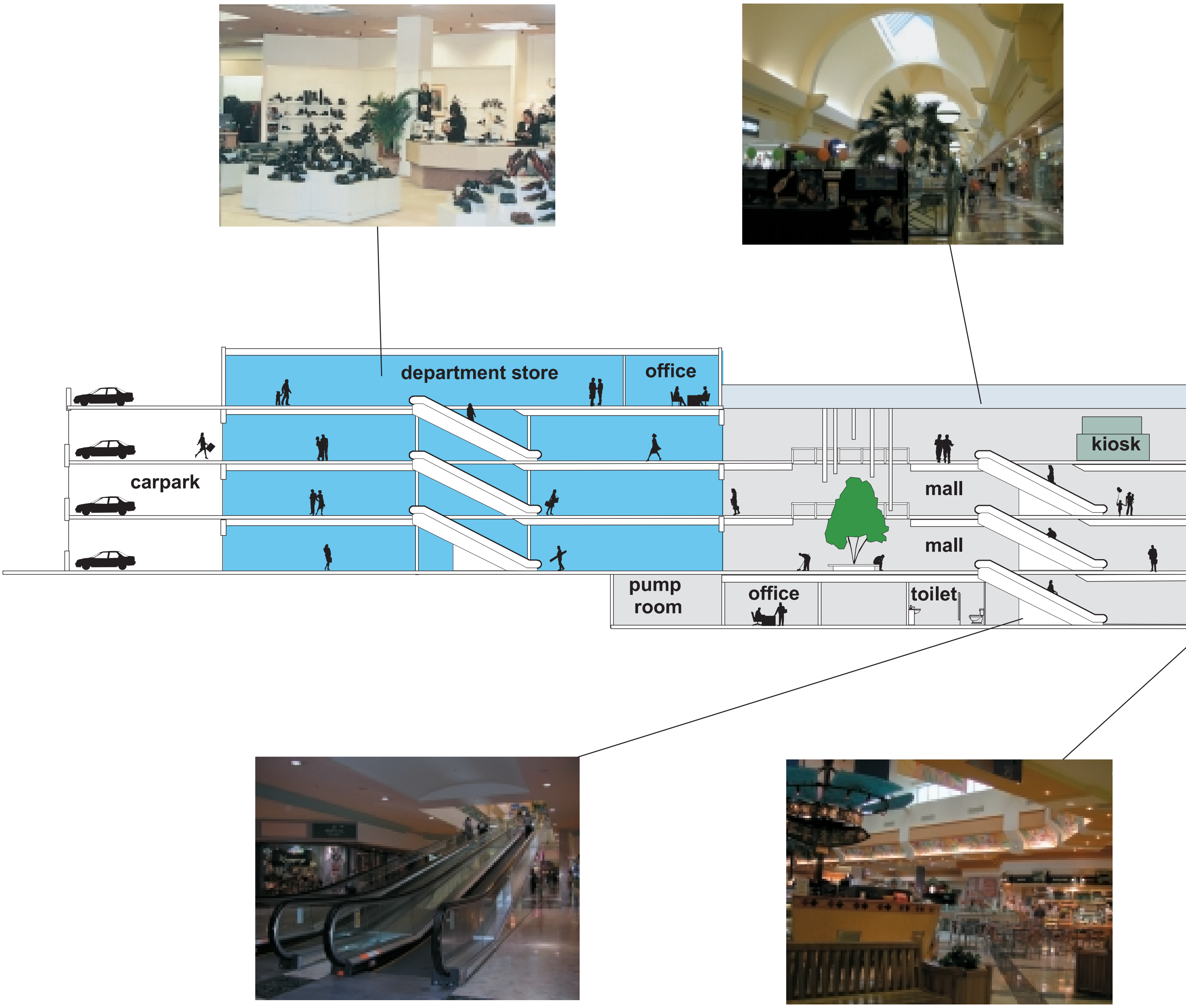
Smoke movement in model building

Behavioural Study

A review of emergency incidents in shopping centres and a series of interviews with shopping centre staff and management was undertaken [9]. On the basis of this work the following observations are made:

- alarm is unlikely, by itself, to initiate evacuation
- the presence of dense smoke in part of the building is a much more effective cue and will be sufficient for people to move away from that area
- the decision to evacuate or move away from the fire-affected area will be positively reinforced by the presence of wardens and staff
- the presence of a crowd of people moving in a particular direction (towards an exit) will also have a reinforcing effect on those who have not started to move
- if the fire is sufficiently large that other levels of the mall begin to experience dense smoke, then evacuation of these smoke-affected parts will be initiated
- the natural tendency of staff is to guide people towards the major entrances (exits) that are commonly used by occupants. There is a fear of using unfamiliar exits and these will only be used if there is no alternative

PARTS OF SHOPPING CENTRE BUILDING



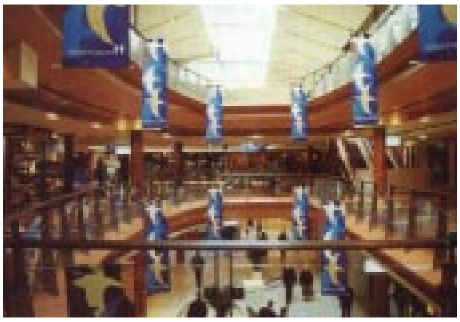

atrium
retail
cinema
mall
mall
mall
mall
specialty shops
major store
storage
food court
loading bay

BUILDING CHARACTERISTICS

Physical Characteristics

Overall Building

Modern shopping centre buildings are generally constructed as large plan area, low-rise buildings where the shops are connected at one or more levels by means of a large covered area or mall. A variety of shops including specialty shops, major stores, food courts, cinema complexes, and recreational facilities are all part of the modern shopping centre. Car parking levels are also provided and may be located below the shopping levels or to one side with direct access into the building.



The trend towards large, open-space buildings with high levels of natural lighting, whilst at the same time providing protection from the weather, has been achieved through the provision of multi-level covered walkways to form shopping malls or atriums.

Mall

The mall is essentially the main part of the building that provides access to both major stores and specialty shops at all levels within the building. Direct access from street and carpark into the mall are usually provided.

In multi-level shopping centre buildings, the levels are usually interconnected by means of escalators/travelators located within the mall. Apart from the escalator openings, the floors of the mall above ground level are also perforated, to give an “openness”, typical of modern shopping centres. The mall often has a vaulted roof.

The quantity of combustible materials within the mall areas is generally low. However, small retail concessions located in mall areas may have significant quantities of combustible material. Alternatively, goods can be displayed in the mall as an extension to a store. At festive times, such as Christmas, significant combustible decorations can be also be contained within the mall space.

Specialty Shops

Specialty shops include shops with a particular theme and having a floor area of less than 1000 m^2.

The densities of fire load in these shops vary significantly, even for the one type of shop [3]. In the case of clothing stores, for example, the fire load density varies from about 15 - 75 kg/m^2 of wood equivalent.

The fire load density in the reserve areas of most shops is less than or equal to the average values for the shops [3]. The exception to this was in the case of footwear shops where the fire load density in the reserve areas is much higher than in the public areas

Care must be exercised in interpreting fire load density data. A high density of combustibles does not necessarily imply that a fire will develop or spread rapidly or that the fire load will be consumed at a rapid rate. An example of a situation which has a very high fire load but which will generally give rise to a slow developing and slow burning fire is a carpet shop which contains rolls of carpet. Despite the apparently high fire load, the surface area of combustibles exposed directly to air is relatively small, and the burning rate will be accordingly low. Bookshops with tightly packed books and magazines can also represent such situations.

In some shops the majority of the fire load is associated with architectural presentation or with furniture required for displaying wares, as opposed to the goods and wares within the shop. In other cases, the goods and wares within the shop constitute the major part of the fire load and the nature and orientation of these combustibles are such that a fast developing fire producing large quantities of dense smoke is possible.

Contrary to what is commonly thought, the ceiling space above specialty shops is usually continuous because the walls do not go up to the floor slab above.

The exceptions to this are for situations where security is critical such as banks and jewellers. Walls are not required to go up to the floor slab by the BCA. This would seem to have some implications for fire spread, should a significant fire develop within a shop. The presence of combustibles (including combustible insulation materials) within this space should be avoided, and the construction of occasional bulkheads within the ceiling space should be considered. This is addressed further in this publication. The storage or use of combustibles within the ceiling space should be discouraged.

Major Stores

These includes shops with a floor area greater than 1000 m^2 including both single storey variety and multi-level department stores.

Approximately 10% of the floor area of these stores is used for storage and is not directly available to the public. In the public areas, the fire load density is marginally greater than that associated with a specialty shop having the same type of goods.

Typically, storage areas will possess a much higher fire load than the public areas. From a fire-safety viewpoint, it is difficult to physically separate such areas from the public areas, although substantial construction may be provided between these areas. However, the presence of openings will minimise any value that this will have in a fire situation.

Access into major stores is via the mall or from adjacent parts such as carparks. All emergency exits from these stores are alarmed for security reasons and are therefore never used, except in the event of an emergency.

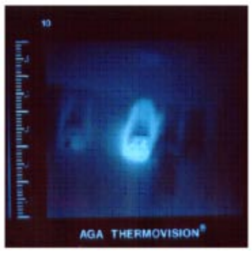
The exterior walls of major stores are always extended to the underside of the floor slab above. This is primarily done for security reasons.

Multilevel department stores incorporate escalators or travelators which provide access between levels. Unimpeded access to and from the escalators is necessary to assist traffic flow within the store. This functional requirement makes it very difficult to provide any form of realistic compartmentation between levels.

Operational Characteristics

In a major shopping centre the specialty shops are leased, and although the occupiers are able to modify the décor—internal layout including ceilings and walls—the ultimate responsibility for the process by which such changes take place resides with Centre Management. Thus, for specialty shops, centre management must give approval for any modifications. On the average, specialty shops are modified about every five years. In well administered centres, procedures for hot work and sprinkler isolation must be followed and approval given prior to the commencement of work. Subcontractors must be approved and inducted prior to work commencing.

The auditing of the storage of goods—particularly of combustibles in relation to potential heat sources (eg. switchboards)—is a sound practice in many centres. Furthermore, the surveillance of power distribution equipment and upgrading of electrical wiring and lighting is aimed at minimising power failures and potential fire starts.



High levels of surveillance are a characteristic of many shopping centres. This is achieved through the presence of security staff combined with camera surveillance, but also due to the large number of staff within the centre. The likelihood of fire detection is further increased by the presence of large numbers of shoppers.

The number of shoppers varies by time of day, time of the week and time of year. Events such as special sales or special times of the year result in populations approaching those that would be obtained by applying BCA Clause D1.13(a) to the building. However, the ninety percentile population can be taken as 50% of this value.

Fire-safety training is an important activity in many shopping centres. This includes training in:

- fire awareness and what to do
- the use of fire-fighting equipment such as extinguishers and hose reels
- roles and responsibilities during evacuation

The involvement of specialty shop staff with fire-safety training, warden activities, and evacuation exercises is the prerogative of Centre Management. However, this can be difficult due to the part-time nature of employment and the fact that staff are constantly changing.

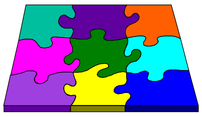
In the case of major stores (including department stores), fire-safety training and responsibilities are usually designated from within the stores but good communication with Centre Management is important.

FIRE SAFETY ASPECTS

Introduction

A rational engineering approach which takes into account the unique characteristics of these buildings is essential to ensure cost-effective construction and high levels of fire safety. In this context the term “fire safety” should be taken as referring to both “life safety” and “property protection”. It is the opinion of the authors, that if the building is properly designed for life safety (which is primarily the concern of the BCA), then it will possess a level of protection against property loss. This matter is considered again later in this section.

Factors Important for Fire Safety

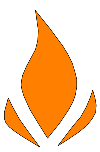


There are many factors that have an influence on the level of fire safety offered by a building. Some of the more significant factors are listed below:

- numbers and types of fire starts
- likelihood of fire suppression by the occupants
- reliability and effectiveness of the detection and alarm systems
- communication systems
- emergency procedures and staff training
- reliability and effectiveness of the sprinkler system
- fire characteristics (flames and smoke)—rate of spread, size, severity
- means of evacuation
- number of occupants and their behaviour
- reliability and effectiveness of the smoke control system
- the action of the fire brigade
- performance of the building structure

A fire-engineering approach to the design of these buildings requires systematic consideration of such aspects as smoke management (smoke control and occupant evacuation), fire extinguishment and fire fighting, and the structural adequacy of the building as it relates to occupant safety. The above aspects are particularly dependent on the choice of design fire and this, in turn, must be determined from the range of possible fire scenarios.

Fire Initiation and Development



To state the obvious: if the initiation of fire within a building could be prevented, there would be no need to invest in expensive fire-safety measures. This, of course, can never strictly be the case, but it may be possible to significantly *reduce* the rate of fire starts—especially through the application of hardware and sound management practices. It is always *better* to prevent a fire start than to attempt to find ways of handling a very large fire—assuming, of course, that it is even *possible* to deal safely with large fires in shopping centres[1].

Statistics

According to [6], 36% of all reported fires in shops in the USA are due to heat from electrical equipment arcing or overloading and 15% are due to fuel fired or powered objects. Equipment of one sort or another (electrical and otherwise) is involved in at least 50% of all fire starts with 39% of these being associated with electrical distribution equipment, 22% with heating and air conditioning, 17% with appliances, 7% with service and maintenance equipment, and 10% with cooking.

Along a similar theme, it is interesting to note that in Switzerland, recent statistical surveys found that 53% of *building losses* were associated with electrical fire starts. As a result, the frequency of survey of electrical installations in buildings has been increased, and residual current protection devices are being subsidised by the regulatory and insurance organisation GVB/AIB[2] [12].

Probability of Fire Starts

An estimate of the average probability of fire starts can be obtained by using a rate calculated for retail buildings [9] and multiplying by the total floor area of these areas. This rate is 2.5×10^{-4}/yr/m^2 and includes the fire starts which are *not* reported to the fire brigade. This rate is an average estimate based on fires in all retail buildings – not just shopping centres. It takes no account of higher levels of housekeeping, auditing, or the use of earth leakage residual current protection. These latter factors can have a significant effect on reducing the incidence of fires.

It is known from retail fire statistics that about 70% of fires occur during the occupied hours.

Although it is possible to estimate the number of fire starts associated with a particular building during the occupied hours, it is necessary to determine the range (and corresponding severities) of the resulting fires. Again, it is known from overseas fire statistics [6], that at least 80% of these fires will be so small that they will not result in the attendance of the fire brigade. Of the remaining 20% of fires that will be attended by the fire brigade, more than 75% will be confined to the object or area of fire origin through the action of the occupants and/or the fire brigade. The latter fires are likely to have little impact on either the occupants or the structure of the building. In non-

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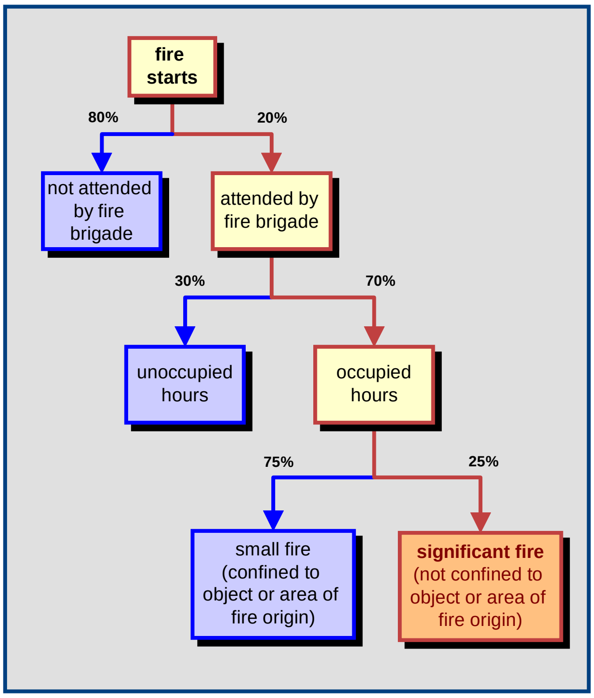
1 This strategy is sensible from both a life safety and property protection (including continuity of business) viewpoint and is adopted in many industries where there are hazardous materials or where the consequences of a major fire cannot be effectively designed against.

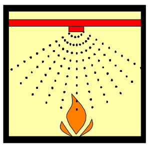
2 A Swiss organisation responsible for operation of the fire brigades, building insurance, and building regulations in the Canton of Bern in Switzerland.

sprinklered situations, it follows that, on the average, 95% (100-20 x 0.25) of fires that start during occupied hours will be small but about 5% of fires will become significant. These are average numbers and it is likely that in buildings with sound management practices, a much lower percentage of fires will become significant.



The presence of sprinklers within these buildings provides an *additional* mechanism for limiting fire size.

Sprinkler Effectiveness



Sprinklers are an essential part of good fire-safety design and their effectiveness is very important. The effectiveness of a component or system can be defined as:

effectiveness = reliability x efficacy

Sprinkler efficacy is defined here as the ability of the sprinkler system to function in accordance with AS 2118 [13] assuming that the system has activated. Sprinkler reliability, on the other hand, is concerned with whether the system will activate (deliver water) and takes into account such matters as isolation of the system and failure of the water supply. These terms can each be represented numerically by a number between 0 and 1.

Sprinkler Efficacy

The efficacy of a sprinkler system in controlling a fire is a function of:

- the type and arrangement of fuel
- the geometry of the room and the arrangement and type of sprinkler heads
- whether the area in which the fire occurs is fully sprinklered in accordance with AS 2118 or whether only parts of the building are sprinklered

Subject to adequate positioning of sprinkler heads in relation to higher racking, and the absence of partial sprinklering, the efficacy of sprinklers can be taken as close to 100%. Otherwise, based on the analysis of statistical a value of 97.5% may be adopted (cf. 93% for the USA).

Sprinkler Reliability

The reliability of sprinkler systems in Australia and New Zealand is generally accepted as being high.

It is vitally important to consider this issue for modern shopping centre buildings and to understand what factors have most influence. It is found that the factor that has the greatest influence on reliability is the isolation of the system to allow tenancy upgrades and modifications.

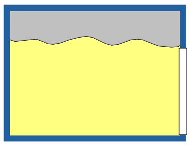
The reliability of a sprinkler system depends very much on how it is managed with respect to modifications taking place within the building.

If the sprinkler system is soundly managed, the following average values of reliability can be adopted [9]:

- sprinkler zones associated with specialty shops **98.50%**
- sprinkler zones associated with major stores **99.50%**

Sprinkler systems associated with shopping centres should be designed and managed to achieve the above levels of effectiveness.

Effectiveness of Smoke Control Systems



Where mechanical exhaust and/or natural venting are critical to the achievement of the *design principles* given in the following sections, the reliability of the systems should be demonstrated to be greater than 0.90 and the impact of external environmental conditions (temperature and wind) and smoke temperature, on the efficacy of the systems taken into account. Simple systems are more likely to achieve high levels of reliability than more complex systems. In some centres, parts of the smoke extraction system are used for normal operations[3]. This is a good practice and should be encouraged.

Natural venting systems are more likely to be effected by environmental conditions, whereas mechanical extraction systems may be significantly effected by the temperature of the smoke in several ways. As the temperature of the smoke increases, the volume of smoke expands and the efficacy of an extraction fan will be less than at lower temperatures. Should the temperature become too high, the fan will stop due to failure of wiring or other components.

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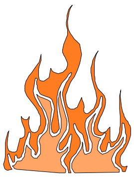
[3] For example, the roof extraction fans may be operated regularly to assist with the removal of stale air from the mall.

Information relevant to assessing the efficacy of systems is given in a number of references [14-16.

One study on the effectiveness of simple mechanical extraction systems is given in [8].

Fire Scenarios

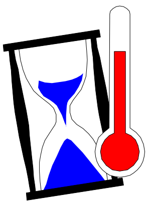


In the Fire Engineering Guidelines [10], the term *fire scenario* appears to cover all details associated with the presence of a fire in the building including the fire itself; detection and suppression, occupant avoidance, smoke management, flame spread, alarms, and fire brigade intervention.

For the purpose of this document, given the design approach adopted, the particular aspects of the fire scenarios that need to be defined at the start of the design process are the characteristics of the Design Fires and their locations.

The locations of the Design Fires should be chosen so as to represent likely worst-case situations. As a general rule, fires in the lower levels of a building are more critical than in the upper levels. Nevertheless a range of upper and lower locations should be chosen. The possibility that exits could be blocked by the fire should also be taken into account.

Design Fires



A fire-engineering approach to the design of these buildings requires the adoption of appropriate design fires. In this regard, it is important to understand that the *same* design fire must be used when considering each element of the fire-safety system whether it influences occupant evacuation, management of the smoke, or the structural stability of the building, etc.

The risk level associated with a particular event can be represented by the following equation:

risk level = likelihood of event x consequences

Thus, rare events with major consequences may result in significant levels of risk. However, it is an accepted principle of risk management that it is better to attempt to reduce the probability of occurrence of events with major consequences than try to design for these events.

It follows that it is better to seek to eliminate the possibility of occurrence of a severe fire (with major consequences) than try to design a shopping centre building for fire safety when exposed to such a fire. This principle should be used to guide the choice of design fires and the fire-safety strategy adopted for building design and management.

Recommended Fires

The design fires associated with these buildings should ordinarily be the relevant sprinklered fires (C2 fires, see p3) taking into account the effects of fuel geometry and possible shielding. Guidance on these matters is given in the section *Smoke Development and Management*. In areas such as parts of the mall where sprinklers on the roof of the mall (if present) may not be effective, and in the absence of other sprinklers, the fire should not be less than 2 MW [16].

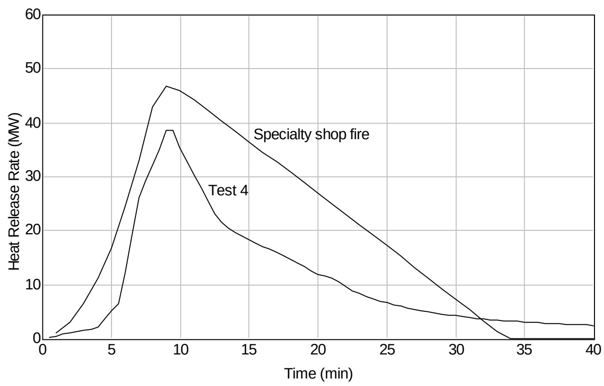
Other Considerations

If the risk level associated with the chosen design fires (sprinklered fires) is considered to be unacceptably high, then it will be necessary to reduce the risk level through design changes through the application of sound risk management principles (AS/NZS 4360 [17]). These measures will reduce the risk through:

- reducing the number of fire starts
- reducing the number of growing fires

This is achievable in managed shopping centre buildings.

Should the building be designed for a C3 fire? One such fire was suggested in [9]. This fire is shown below and corresponds to a fully-developed fire associated with an "average" SOU but also corresponds fairly closely with the full-scale fire tests mentioned earlier.

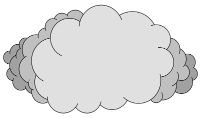


The following should be noted:

- the bigger the fire, the greater the uncertainty in performance of fire safety systems
- recent testing indicates that it will be virtually impossible to predict the spread of smoke in these buildings for such a fire
- recent testing indicates that it will be virtually impossible to design these buildings for such a fire—to achieve tenable conditions during evacuation
- a C3 fire has the potential to rapidly grow and spread—it is unstable

A C3 fire **should** be considered. However, the risk associated with it should be lowered, not by trying to deal with the consequences, but reducing the probability.

Smoke Development and Management



It is known that a primary cause of death in fire is due to the exposure of the occupants to the products of combustion—smoke; although burns are also commonly noted as a contributing factor. Smoke is generated by combustion and contains, in addition to toxic gases, small particles of matter suspended in air. It is these particles that indicate the presence of potentially toxic gases and assist in the containment of heat within a smoke layer. The temperature of a hot smoke layer can also present a threat to the occupants.

Design Strategies

In the event of a fire, because it is hotter than the ambient air, smoke will tend to rise and move through the building including enclosures and pathways used by the occupants—thereby putting them at risk.

Smoke management, when understood in the broadest sense, is concerned with managing smoke within the building such that the likelihood of exposure of the occupants to *debilitating smoke* is minimised. Other objectives include assisting the activities of fire fighting through maintaining visibility and minimising the property damage associated with smoke. Strategies for achieving these objectives include:

- keeping the fire small—such fires generate less quantities of smoke
- providing adequate venting/extraction where appropriate—removing smoke from the building and away from the occupants
- providing barriers to minimise the spread of smoke
- providing adequate egress paths and evacuation strategies—to quickly move people away from the smoke-affected areas

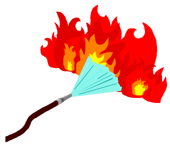
Thus, smoke management is about managing the smoke in relation to the building occupants. The term *debilitating smoke* was used above to emphasise the fact that not all exposures to smoke will lead to serious injury or death. Injuries can vary from minor irritation to serious injury and death—the seriousness of the injury being a function of the density and content of the smoke and the length of exposure to it.

The people within the building will behave similarly to people in other buildings where the occupants are awake and aware, and the presence of dense smoke will serve to reinforce the need for occupants in the vicinity of the fire to move away from the fire-affected part of the building. Those closest to the fire-affected areas will respond first due to the greater intensity of cues; and this is appropriate as they will be at greatest risk.

In the event of a significant fire, occupants will seek to move out of the enclosure of fire origin (and eventually out of other adjacent enclosures) via familiar routes. It is necessary to ensure that there is sufficient time for evacuation from the enclosure of fire origin. Sufficient natural venting/mechanical exhausting *may* be necessary to achieve this outcome.

In many situations the occupants will move into a mall and then attempt to follow a familiar route. Thus it is recommended that malls be designed as *safe* places such that in the event of the design fires, the occupants will not be threatened once they enter this area. Occupants should be able to remain in the mall for a very long time without being subject to untenable conditions. This will be achieved through the provision of effective smoke control systems within the building. Sufficient tenable egress pathways from the mall must be provided to allow eventual movement to other safe places or to outside. However, "special-purpose" fire tunnels are unlikely to be used and are suggested to be unnecessary.

Fire Fighting



As previously observed, a high proportion of fires in buildings are extinguished without the fire brigade being called, and even when they are called, more than 80% of these fires are confined to the object and area of fire origin. These facts suggest that the occupants of the building have an important role in early fire fighting, or in controlling the fire until the fire brigade arrives. This emphasises the importance of adequate fire-fighting facilities and staff training.

The fire brigade's charter relates not only to safety of the occupants of the building but also to the protection of property—including the building in which the fire originates. They are not expected, however, to take unnecessary risks. The BCA, on the other hand, is primarily concerned with maintaining a high level of life safety, although it is concerned with minimising the damage to *adjacent* properties and buildings. The latter objective is less relevant for these buildings as they are generally well separated from adjacent properties.

The fire brigade is an important part of the fire-safety system, and in the event of an alarm, may be considered to have the following specific functions:

i. where there is no other evidence of fire, investigate the situation and the probable cause of the alarm

ii. extinguish fires that are small or that are being controlled by the occupants or a sprinkler system

iii. participate in evacuation of the occupants in the event of a significant fire—if that has not already occurred

iv. undertake any reasonable measures to control, and finally extinguish, a significant unsprinklered fire

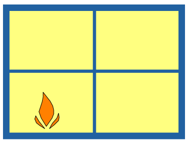
v. limit fire spread to other parts of the building or other buildings

Factors which can have an important influence on the *ability* of the fire brigade to fulfil the above functions include:

- time of receiving an alarm
- activities and timing including travel and setting-up times
- fire-brigade facilities
- speed of growth of the fire

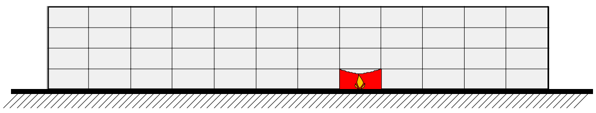
The time for arrival of the fire brigade to a shopping centre is estimated as 10 minutes, and in practice, is likely to be considerably less. Estimates of times for setting up, gaining access to the fire, and achieving fire suppression must also be made.

Structural Adequacy

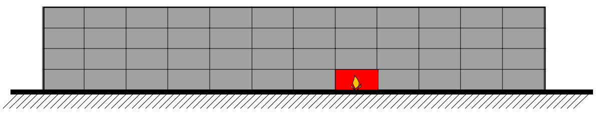


Section C (Fire Resistance) of the BCA gives a series of performance requirements, some of which relate to the building structure. A careful study of these requirements reveals that the building must be designed to provide safety for the occupants and fire fighters, and so that fire does not spread to other properties. The latter matter is rarely an issue with these buildings due to the fact that they are generally well separated from adjacent buildings, and the buildings are sprinklered, whilst the former is achieved by designing for the appropriate design fires.

Sprinklered fires have little impact on the structure of the building as evidenced by the results from the sprinklered fire tests [7]. Even a C3 fire would have a much greater impact on the occupants of the building than the structure. This is because the smoke from such a fire will have a *global* impact on the building whilst the structure will only be affected *locally*.



heat impact is local

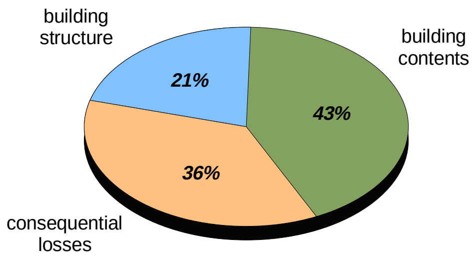


smoke impact is global

Furthermore, it is recognised that parts of buildings exposed to local fires will behave much better than expected from individual member behaviour. This is due to the redistribution of load and the mobilisation of other mechanisms of load resistance.

Property Protection

The issue of property protection is of importance to both owners and operators of shopping centre buildings. From overseas statistics [18] the average costs associated with fires in buildings are divided as follows:



Consequential losses include those associated with the loss of business, and in the case of shopping centre buildings, it is likely that these will be much higher than the above proportion. In any case, it can be seen that the building structure losses are a small part of the total losses.

The *most* effective way that a property can be protected against fire *is to not have a fire start in the first place*. This cannot always be achieved in these buildings but routine surveillance and housekeeping audits will be effective in reducing fire incidents. These activities therefore offer value with respect to property protection.

If a fire start cannot be prevented, the next best action is to confine the fire to the object or area of fire origin through the action of staff or other occupants. The majority of fire starts (70%) occur during the hours that the building is occupied and are associated with the demand for services and electricity and the activities of the occupants. However, during occupied hours, the presence of people will result in the fire being mostly extinguished before the sprinklers are able to activate. This is less so during the “unoccupied” times when only a skeletal staff occupies the building; but even then, it appears that many of these fires will not go beyond the area of fire origin. Housekeeping, the establishment of fire-response procedures, and the training of staff in such procedures can provide additional levels of property protection.

A soundly managed sprinkler system is the remaining way of restricting a fire to the area of fire origin—although activation of sprinkler heads may result in water damage. Nevertheless, this damage will be substantially less than that experienced if the sprinklers are not present or functioning.

High levels of structural fire resistance will generally not provide high levels of property protection.

Managing Fire Safety

Considering the number of major shopping centres and the time that these have been operating, there has been a notable absence of major fires and no deaths in these buildings. The reasons for this are:

- significant fire starts are rare
- fire starts are picked up early and fires are usually extinguished before sprinkler activation
- sprinkler systems are generally reliable

The above observations are a reflection of the benefit of having many people in the building who are awake and aware and of sound management practices. Fire-safety management is often driven from an insurance or business perspective; however it is also critical from a life-safety viewpoint.

Management of fire safety is about managing the risks associated with fire, and as a consequence, the general principles of risk management apply. As noted previously reference should be made to AS/NZS 4360.

OCCUPANT AVOIDANCE

Design Strategy

To provide means for safe egress of occupants put at risk by a fire.

Design Principles

i. All enclosures[4] and areas within the building shall be designed to avoid entrapment.

ii. All enclosures and areas shall have sufficient egress paths to allow evacuation to a safe place, open space, or roadway, prior to the achievement of untenable conditions.

iii. An evacuation plan shall be developed and implemented.

Details

In designing these buildings for evacuation, it is important that entrapment is avoided as this has been found to be one of the major sources of deaths in buildings. This is normally achieved through the provision of sufficient alternative egress paths from each enclosure or area of the building. This is the purpose of the first principle. For the purpose of this publication, the mall walkway at each level is regarded as an area, not an enclosure, as their principal purpose is to provide access to specialty shops, major stores, carparks, etc, on that level. These areas are specifically designed to provide efficient means of movement on a level within the building and are interconnected by stairs, escalators and travelators. In the event of a fire, the occupants will seek to move into and along the walkways. Shoppers may also seek to gain access to carparks or to other levels in their attempt to avoid the effects of a fire.

Egress paths should be taken as those parts of the building that are *likely* to be used by the occupants when leaving that part or area of the building. They include such travel paths as mall walkways, open stairs, escalators, travelators, and fire-isolated stairs. Smoke may flow between levels through voids and care should be taken to ensure, that in such cases, there are adequate paths to lower levels or to safer places within the building.

The *first design principle* may also means that egress paths will, at least, be provided at each end of an enclosure or area. However, this may not be practical and the BCA and current experience suggest that this principle need not apply to enclosures and areas with a maximum plan dimension of 20 m or less. However, each situation needs to be carefully evaluated.

The *second principle* is concerned with the provision of adequate egress such that the time for evacuation is less than the time to untenable conditions. The evacuation time is a function of the following factors:

- the decision to evacuate
- the number of people
- the type of exit
- the choice of exit
- the distance of travel
- the exit widths
- speed of travel
- the amount of queuing
- the availability of safe places

The exit width requirements in the BCA appear to have worked well with respect to facilitating the safe movement of large numbers of people through these buildings under non-fire conditions. Designers need to be cautious in varying from the exit width requirements determined in accordance with the area/person values given in BCA clause D1.13(a).

As far as exits in major stores, department stores and specialty shops are concerned, it is also recommended that these comply with the existing BCA requirements (ie. based on the floor area per person numbers given in the BCA) with the exception that the mall should be regarded as a safe place such that an *entrance* into the mall can be considered as a *required* exit.

However, it is *additionally* recommended that shops and stores be permitted to have only one exit (taking the doorway into the mall as the exit) provided the maximum distance of travel from any part of the shop to that exit is less than 20 m.

Variation of travel distance and *exit* spacing within a *mall* may be appropriate and should be the subject of calculation. Guidance on these matters is given within *Methodology*.

Safe places are now considered. These may be considered to correspond to roadways or open spaces (as per the BCA). However, *malls* and *adjacent carparks* should also be designed as *safe places*. A *mall* should be designed as a safe place by complying with the design requirements given in the section *Smoke Development and Management* and by providing means for the occupants to move between levels in the mall and/or to separate parts of the building functioning as connected “safe” places such as an appropriately designed carpark or the outside roadways. Potential means to achieve this include open stairs, travelators/escalators, and direct access into connected safe places (e.g. appropriately designed carparks, open spaces). Such means of egress, at any level of the mall, should include all of the following:

- be not less than three in number
- be accessible from both sides of the mall at that level
- be spaced not more than 75m apart

[4] The term enclosure refers to a part of the building which is surrounded by wall, floor and roof construction which may be fire-resistant but which may contain significant voids.

- be provided within 20m of each end of the mall

These specific recommendations are aimed at avoiding the possibility of entrapment within the mall and ensuring that there are sufficient means to move the occupants out of this space should this be necessary.

Although open stairs, escalators and travelators have been proposed as potential means of moving occupants from one level of a mall to adjacent less-affected levels, this will only be possible if these are tenable at the time. The presence of smoke in the associated voids will act as a deterrent to their use. Stopping and eventual reversal of the upwardly moving escalators will be desirable and this should form part of the *evacuation plan*.

An adjacent carpark may be considered as a safe place provided it complies with the requirements given in the sections *Smoke Development and Management* and *Fire Spread and Management*.

The *third principle* is fundamental to having a high level of fire-safety within the building. An *evacuation plan* which addresses the following matters should be developed:

- training and education of staff
- lines of authority in an emergency
- cue reinforcement
- communication between staff
- assistance of occupants with evacuation
- agreed preferred exit paths for various scenarios and management thereof
- interaction and communication with the fire brigade
- emergency drills

This is further considered in the section *Management of Fire Safety*.

The second and third principles require the calculation of times for evacuation. This can be undertaken using the methodology given below and should take into account the possibility that exits could be blocked by the location of a fire or become untenable due to smoke.

The time for evacuation should be determined for each part of the building where untenable conditions could develop as a result of the adopted *design fires*. For each situation considered, it is necessary to show that occupants can escape prior to the achievement of untenable conditions. This is considered further in the section *Design for Smoke Management*.

Methodology

EXIT Evacuation

The time for evacuation of the occupants from a particular enclosure or area within the building should be determined from:

$$t_e = t_{pm} + t_m$$

where t_{pm} is the pre-movement time and includes all of the events required to make the decision to evacuation, and t_m is the total movement time for the occupants to move to a safe place.

Pre-movement Time

Within the enclosure of fire origin it can be assumed that the decision to evacuate will be made before sprinkler activation—probably at the point that it is recognised that occupant fire fighting is not likely to be effective.

However, in areas or enclosures away from the enclosure of fire origin, it is likely that the occupants will move away after sprinkler activation. As this occurrence will be accompanied by quantities of smoke and steam, it is reasonable to assume that those closest to the fire-effected enclosure or area will begin to move first. Evacuation of other parts, further from the fire, will only commence as smoke becomes evident and is perceived as a threat. Thus "pre-movement" time is a function of the time that the smoke begins to threaten or when the occupants are directed to evacuate by management. At the location of fire origin, the pre-movement time can be effectively ignored.

Total Movement Time

The total movement time shall be determined taking into account:

- the available tenable egress paths (paths may be blocked by smoke and/or flames)
- the speed of travel
- queuing within the egress path
- the evacuation plan
- the times that occupants in various parts of the building will begin to evacuate

The final point recognises that evacuation of a shopping centre will not commence at all points at the same instant of time. As occupants in other parts of the building become more aware of the presence of a fire, threatened by the effects of the fire, and/or guided by staff, they will begin to evacuate.

For the purpose of calculating total movement time, the *population* of each area of the building may be based on the following numbers:

- *mall & upper level shops with restricted access* — 10 m^2/person
- *other shops* — 6 m^2/person

Movement Hierarchy

The following movement hierarchies are considered appropriate as should be reinforced the evacuation plan:

- *Specialty Shop of Fire Origin*—Usually there is only one exit/entrance to these stores and therefore movement will be into the mall. Once in the mall, people will move away from the fire area.
- *Neighbouring Specialty Shops*—People will remain within the shops unless they are instructed to leave by the shop management. The decision to evacuate may result from the observation of smoke in adjacent parts of the building and/or a concern to minimise smoke damage within the shop by closing the front entrance, or it might follow as a result of an instruction from a Warden. Evacuation will then be via familiar entrances/exits into a carpark or open space on the same level, but if these are not available, directly into the mall[5].
- *Major Store of Fire Origin (single level store)*—In this case, the occupants will move towards the familiar entrances/exits. It is only where these are not accessible, due to the location of the fire, that the emergency exits will be used. Thus people will generally move into the mall or to outside.
- *Department Store of Fire Origin*—A department store is a multi-level store where the normal transport between levels is by escalator but where entrance/exit from the mall is a possibility. At some levels, an entrance from the street or an adjacent carpark may also be provided.

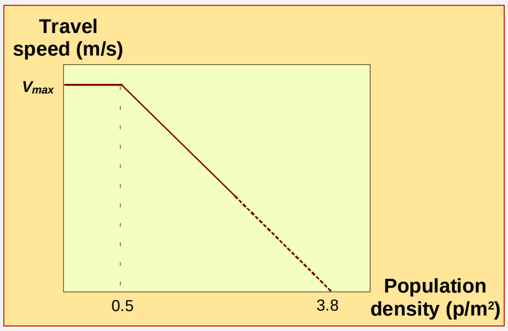
  If familiar entrances are available to the level of fire origin then movement will be towards these. If these entrances are not accessible, due to the location of the fire, then the emergency exits will be used.

  If the only way of getting to a level is by means of an escalator then this will be used if the fire is on that level, unless the location of the fire prevents its use or there is considerable queuing at the escalator. In these cases the emergency exits will be used. If, on the other hand, the fire is below this level, then only the emergency exits will be used due to the presence of smoke in the escalator well.
- *Neighbouring Stores (Major and Department Stores)*— People will remain within the stores unless they are instructed to leave by a Warden. The decision to evacuate may result from the observation of smoke in other adjacent parts of the building and/or a concern to minimise smoke damage within the store by closing the store, or it might follow as a result of an instruction from a Warden. Evacuation will then be via familiar entrances/exits into a carpark or open space on the same level, but if these are not available, into the mall.
- *Mall*—In the case of people within a mall, some of whom will have evacuated from shops and stores where the fire was located and others from stores further away from the fire, movement to "safer" areas will eventually be sought by the occupants by means of familiar entrances/exits. This latter term may be taken as any form of entrance/exit which is used to enter or leave a particular level of a mall such as entrances to a carpark, normal street access, or for the upper levels stairways, escalators, travelators, provided they are tenable.

Calculation of Movement Times

These must be determined taking into account:

- The variation of travel speed with population density.



Travel Speed vs Population Density

- The effective widths associated with the egress paths [19]
- The appropriate population densities at the narrowest parts of the egress paths.

As far as the latter point is concerned, the narrowest part of an egress path will dominate the flow along the path. The flow capacities of these paths should therefore be determined by assuming a high value of population density (and correspondingly reduced speed of travel) for the narrowest width location. However, the chosen value of population density should be *less* than that at which optimum flow is achieved.

V_{max} may be taken as 1.2 m/s for horizontal travel and 0.9 m/s for travel down stairs.

The flow rate down stairs needs to be determined based on persons on every second step. The flow rate for escalators/travelators can be taken as 1.25–1.5 persons/s.

Hand calculations [9] can be used to estimate the total movement time associated with a major store or department store.

[5] Store owners may wish to evacuate stores and close front entrances due to perception of smoke damage.

SMOKE DEVELOPMENT AND MANAGEMENT

Design Strategy

To provide means for the safe egress of occupants put at risk by a fire.

Design Principles

The building shall be designed so that:

i. areas and enclosures shall remain tenable for a period sufficient to allow evacuation from the area or enclosure

ii. egress paths from each area and enclosure shall remain tenable for the expected duration of evacuation from that area or enclosure

Details

Achieving tenable conditions for the various spaces within a shopping centre is the focus of this section.

The above design principles mean that for any enclosure or area, the time to untenable conditions must be greater than the time for evacuation of that part of the building. The time for evacuation must be determined in accordance with the section *Occupant Avoidance*.

The various parts of a shopping centre that must be considered are:

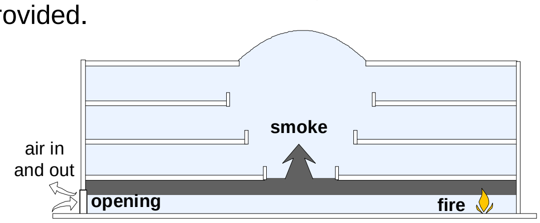
- specialty shops
- major and department stores
- malls
- adjacent carparks that are directly connected to the centre

Due to the relatively small size of the specialty shops (defined as having an area of less than 1000 m^2), the time to evacuate a specialty shop can be assumed to be always less than the time for untenable conditions to be achieved.

In the case of major and department stores, it is necessary to demonstrate that tenable conditions can be maintained until evacuation is complete.

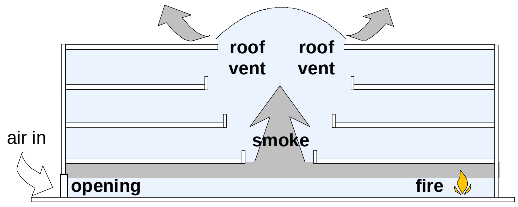
As explained previously, malls and adjacent carparks should be designed as safe places since the occupants will tend to move into these areas in the event of a fire. These parts are to be designed to remain tenable such that they do not present a threat to the occupants. However, before considering how this might be achieved in a mall situation it is helpful to consider some findings with respect to the movement of smoke through horizontal openings as will be found in a mall.

The situation shown below represents a four storey mall where openings are provided in the floors. However, at this stage, no roof vents are provided.

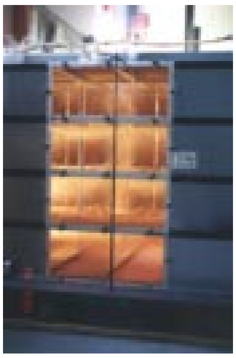


The diagram also shows an opening to outside on the lowest level through which air can be drawn and smoke vented. There are no other openings to outside. Given a fire on the lowest level, the height of the smoke will largely controlled by the area and height of the vent to outside. If there was no vent to outside, then the height of the smoke is dependent on the size of the reservoir for a given size fire. It is interesting to note that the presence of the floor opening has little influence on the level of smoke in the lower level. Eventually however, smoke migrates upwards to the other levels, and depending on the size of the fire, those levels will progressively fill with smoke. The lowest level will initially have the densest smoke.

A vent in the roof is now introduced and this greatly accelerates the movement of smoke to the upper levels and in time affects the level of smoke in the lowest level—but not initially.



As the smoke flows upwards through the holes most of it passes through the vent to outside. However, as the smoke passes the edges of the holes it spills into these upper levels and is mixed, resulting in the smoke not being well layered in these upper levels. This is illustrated by the model test shown on the right.



Once again, the lowest level has the densest smoke whilst the upper levels have progressively less smoke. The amount of smoke entering these levels is dependent on the size of the roof vent and the size of the fire. The provision of baffles around the floor and roof openings may not resolve this problem of mixing; nor will the use of roof fans.

The above findings are very significant as they illustrate that if tenable conditions are to be maintained within the mall then the smoke entering the mall must be significantly restricted. This can be achieved through containing or extracting the smoke before it enters the mall or simply keeping the fire small.

Should smoke enter the mall, the presence of roof vents or fans improves the situation significantly reducing the density of smoke at all levels compared with vents or extraction not being provided. To be most effective, the roof vents or fans must be operated as early as possible and therefore cannot be activated by smoke detectors located at roof level of the mall.

Given that the mall is be to a safe place, and the above findings, it is recommended that there is a sufficient number of adequately spaced openings within each walkway level in the mall.

This may be considered to be achieved if:

i. the total area of the openings (*other* than those associated with escalators/travelators and open stairs) in each level in the mall exceeds 5% of the plan area of the mall at that level

ii. at least one opening is provided between each successive pair of open stairs or escalators

iii. the maximum distance between such openings is 75 m

It should be noted that the openings closest to the source of smoke (where it enters into the mall) will "attract" more smoke and minimise the horizontal movement of smoke along the walkway levels to other openings.

An *Adjacent Carpark* can be considered as a safe place provided at least one side of the carpark is at least 50% open and the openings between the carpark and the mall are protected to minimise the spread of smoke into the carpark.

It is considered that adequate separation at openings can be achieved by means of glass doors—provided the doors are able to be closed individually[6] in the event of adverse conditions at that particular entrance to the carpark.

Methodology

Tenability

It is the presence of dense smoke, rather than any smoke, that presents the greatest threat to the occupants. This type of smoke is mostly associated with severe unsprinklered fires, which are not considered as design fire herein.

Tenable conditions may be considered to exist in an enclosure or area if the smoke layer in that enclosure or area is greater than 2 m from the floor. This criterion is considered to be sufficiently conservative that detailed consideration of the smoke hazard is not necessary. If a lower smoke layer height is used, or if smoke is not well layered, then detailed consideration of the smoke hazard (temperature, toxic properties, etc) may need to be undertaken.

Guidance on estimating the toxicity of smoke and its impact on occupants is given in [19].

Estimation of Smoke Volumes

A smoke control system should be designed taking into account the rate at which smoke is produced, the speed with which evacuation can take place, and the paths likely to be followed by the smoke within that part of the building.

The rate of smoke production from a fire depends on such factors as the fire size, the height to which the smoke rises before hitting an obstruction (such as a ceiling, floor, upper deck, etc), and the height of the bottom of the smoke layer.

Design Fires—Sprinklered (C2) Fires

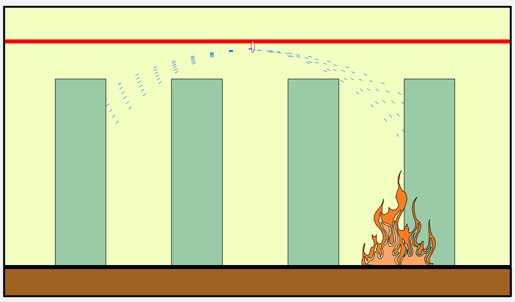
In the case of sprinklered fires, the rate of smoke production is also a function of the level of shielding. In this regard, and in the absence of better information, it may be assumed that there are four types of sprinklered fires—C2-1 to C2-4. These may be assumed to correspond to the following situations:

Category "C2-1"—these are fires where the water is applied to the seat of the fire and there is an absence of racking. It is also assumed that a ceiling is present having a height of not more than 4m. They are considered to be identical to the sprinklered fires experienced with Tests 5 - 9 reported in [7] and are not considered to present a threat to the occupants.

Category "C2-2"—this type of sprinklered fire may be assumed to arise when there is racking corresponding to the "C2-4" or "C2-3" situations but that the sprinklers are positioned above or between the racks. These situations are considered to give a smoke production rate equal to 25% of that associated with an "C2-4" fire.

Category "C2-3"—if the situation is identical to that described for a C2-4 fire, except that the racking is lower (up to 2m below ceiling or soffit if there is no ceiling), then there will not be as great as interference with the application of water to the fire. It is estimated that the rate of smoke production in this case will be about 50% of that associated with an "C2-4" fire.

Category "C2-4"—This situation is considered to give rise to the greatest rate of smoke generation and for the purpose of this report is described as a "C2-4" fire. This fire corresponds to that associated with *high* racking with stacked goods on top such that the total height is within 1000mm of the ceiling or soffit where the closest sprinkler heads are *not* located over or between the racks. These fires may be taken as similar to that associated with Test 1 reported in [7].



In the absence of better data or approaches, the simplified formula given in [9] may be used to estimate the volume of smoke with time. This formula is based on engineering judgement.

The question of buoyancy of smoke is one that is often raised with respect to sprinklered fires.

6 Only the door affected by smoke and hot gases should be closed. The others must remain open to allow normal egress into the carpark.

The buoyancy of smoke is a function of its temperature. In the vicinity of the fire, sprinklers appear to have a "washing" effect on the smoke and to locally mix the smoke so that it does not appear to be buoyant. However, tests have shown that away from the sprinklers, the smoke will be buoyant provided its temperature is slightly higher than the adjacent ambient air. For fires such as a C2-4 fire, the smoke will remain buoyant for substantial distances, whereas for lesser fires, this may not be the case. Small sprinklered fires will only effect small parts of the shopping centre and therefore do not present a substantial threat to the occupants. Furthermore, as indicated above, the concentration of toxic gases in such smoke is likely to be very much less than that associated with a non-sprinklered fire.

Design Fires—Non-sprinklered Fires

These fires are local fires where due to the height of the roof above the combustibles it is unlikely that sprinkler activation will occur or where sprinklers have not been provided. The smoke layer height within an enclosure can be determined using zone modelling. Account should be taken of the following:

- the effect of wall openings
- any air entrainment due to flow of smoke
- the effect of any extraction or venting.

The effect of temperature on the effectiveness of venting and mechanical exhaust should be considered.

The flow of smoke through floor openings, should it occur, cannot be modelled using a zone model and evaluation of this situation, and of the impact on the upper levels, may be based on alternative numerical analysis, or preferably on test data.

Recommended Approach to Each Part

Specialty Shops

As noted previously, it is not necessary to calculate the time to untenable conditions *within* a specialty shop since the time for evacuation will be less.

If the fire is associated with a specialty shop having a reserve area such that there is direct access into the ceiling space (eg. The storage area associated with a shoe store), then the ceiling cavity will act as a reservoir for the smoke.

This will be significant as it will mean that less smoke will be spilled directly into the mall.

Major Stores

The application of the design fires to a major store is distinguished by whether it is single level or multi-level.

(a) Single level major store

Once any natural smoke reservoir within the store is filled, the smoke will spill into the mall unless it is extracted directly from the store.

In the case of C2 fires it should be assumed that the ceiling will be largely resistant to the inflow of smoke unless it has been specifically designed to allow otherwise.

For stores having a plan area width or depth of not greater than 80 m, it is considered that the smoke from such fires can be *regarded* as buoyant over the area.

(b) Multi-level department stores

Multilevel department stores have levels which are interconnected by escalator shafts. It follows that should smoke enter the escalator void, it will find its way on to the upper level being mixed at the edges of the voids and due to the effects of the escalator. This will result in mixed smoke in the upper levels. The appropriate design approach is to prevent smoke entering the void. This can be achieved in two ways:

- extract the smoke at each level
- provide baffles around the edges of the escalator void to prevent inflow of smoke.

Once again the ceiling within a department store should be taken as impervious to smoke unless it has been designed otherwise. For stores having a plan area width or depth of not greater than 80m, the smoke may be *regarded* as buoyant.

Mall

As discussed previously, the mall must be designed to be a safe place which will not threaten the occupants. Significant smoke must therefore be prevented from entering the mall or extracted so as to permit tenable conditions to remain within the mall. In the case of a fire within a specialty shop, the smoke associated with a sprinklered fire should be relatively low in volume and this will be further contained by the shop front and walls. The presence of any void into the ceiling space at the rear of the shop will also provide a reservoir for smoke.

In the case of major stores, designers should seek to prevent the movement of smoke into the mall through proper design of the sprinkler system (to limit the fire size), containment by a reservoir, and extraction.

The spillage of smoke into the mall will be relieved by the presence of vents or fans at roof level. However, it is not possible at this stage to give definitive guidance on estimating gas concentrations and obscuration on mall levels above the fire due to spillage into these levels. Limiting the amount of smoke entering the mall is a key strategy and this is achieved by limiting the fire severity.

The effectiveness of a vent depends on its size and the buoyancy of smoke. Vents located well above a small fire may not be effective in extracting smoke. Extraction fans will be more effective in these situations but these may also be severely limited as air may be drawn from below the smoke layer.

Design Strategy

To provide sufficient means of:

- **detection**
- **fire fighting for the occupants**
- **automatic suppression**
- **fire fighting for the fire brigade**

Design Principles

i. Sufficient means of detection shall be provided.

ii. Sufficient means of alerting staff and fire brigade shall be provided.

iii. Sufficient portable extinguishers shall be provided and suitably located within the building to enable occupant fire fighting.

iv. Sufficient hose reels shall be provided and suitably located within the building to enable occupant fire fighting.

v. A sprinkler system which is commensurate with the hazard shall be incorporated throughout the centre.

vi. A training program for staff in fire awareness and the use of portable extinguishers and hose reels shall be developed and implemented.

Notes on Design Principles

Fire Detection

Fire Detection is required for the following purposes:

i. when the building is occupied, to provide a back-up to occupant fire awareness

ii. when the building is substantially unoccupied, to provide a warning to staff within the building

iii. to initiate the operation of smoke exhaust and venting systems

iv. To provide, in combination with other hardware, an automatic means of notification of the fire brigade (see Fire Brigade Communication and Response).

The most effective form of fire detection during operational hours is associated with the presence of the occupants within the building. Detectors provide a back-up to occupant awareness and associated occupant-staff and staff-staff interaction.

Fire Communication and Response

In the event of a fire being detected by an occupant (non-staff), it is likely that this fact will be communicated verbally to staff. Staff can communicate with Management by telephone; and communication from Management to the Fire Brigade by telephone (including mobile) or by activating a Manual Call Point[7] (MCP) located at Centre Management. For such communication to be effective, it is essential to have a documented and well-rehearsed procedure for notification of the presence of a fire (see section on *Management of Fire Safety*).

MCP's, if provided, should be located to allow notification of the fire brigade by *staff*.

Should a detector (or MCP) be activated, this will result in alarms to Management and the fire brigade. Management will respond to the alarm by assessing the fire situation and providing any necessary back-up. It is at this point that a decision will be made as to whether to initiate evacuation of this part of the building. The decision to activate alarms or warnings using alarm or public address systems will be made at this point.

Suppression

Suppression of a fire shall be achieved by the following means:

- *portable extinguishers*—provided in appropriate locations throughout the Centre to allow for ready access by staff in specialty and major stores, and other areas having a higher than normal potential rate of fire starts
- *hose reels*—provided for use by staff
- *sprinklers*—provided to extinguish or limit the size of the fire
- *action of the fire brigade*—using extinguishers and hose lines. Hose lines may need to be connected to hydrants within the centre. Reference should be made to the section *Fire Brigade Communication and Response*

Details

Fire Detection

Smoke detection shall be provided to allow early activation and operation of smoke exhaust and venting systems (see the section on *Design for Smoke Management*).

Fire Extinguishers

Portable extinguishers to AS 2444 [20] shall be provided in all specialty shops and throughout major stores and in any enclosures where there is power distribution equipment, the cooking of food (eg. kitchens, dining rooms, food and beverage outlets), or the storage of hazardous goods or flammable liquids.

Hose Reel

Hose reels to AS 2441 [21] shall be located throughout the building such that the nozzle end of

7 MCP's might have had relevance in the past. However, with modern means of communication (mobile phones, radios, etc) their relevance would appear to be less. It is not clear that there is good justification for these being provided in shopping centres. Their incorporation in public areas is a source of concern and annoyance to shopping centre management due to nuisance activation.

the fully extended fire hose fitted to a reel, and laid to avoid any partitions or other physical barriers, will reach every part of the building that is likely to contain significant combustibles (> 5 kg/m^2 of wood equivalent).

Sprinklers

The sprinkler system shall be generally in accordance with AS 2118 [13] with the following additional recommendations:

i. within the retail areas—ORDINARY HAZARD III in accordance with AS 2118

ii. within the carpark part of the building–ORDINARY HAZARD II in accordance with AS 2118

iii. areas which incorporate shelving and racks of greater than 3m in height shall be designed to ensure that sprinkler heads are positioned to allow delivery of water to each exposed side of the shelf (see also the section on *Design for Smoke Management*). Sprinkler systems with greater delivery rates may be necessary in these situations

   Note: *Recent trends with high shelving within stores and a greater presence of plastic materials—giving a faster rate of fire growth and greater shielding of the fire from water—has raised concerns as to the adequacy of an OH III system to control some fires. High shelving manifests itself in toy stores, shoe storage areas, and some major stores including variety stores and supermarkets. Furthermore, the spacing between shelves may be substantially less than the sprinkler head spacing and the heads may be positioned well away from the location of a fire.* all

iv. sprinkler valves (including subsidiary valves) shall be monitored

v. sprinkler valves shall be provided to permit each part of the building (major store, group of specialty shops, carpark, etc) to be isolated separately and at each level

   Note: *The reliability of a sprinkler system is dependent on the number of times and duration that the system is isolated. If smaller parts of the building can be isolated without effecting the other parts, this will improve the reliability of the system. It therefore recommended that the various parts of the building such as carpark, groups of specialty shops, major stores, etc, are separately valved and that each level within those groups is able to be isolated independently of the other levels.*

vi. records shall be maintained such that there shall be no confusion as to which sprinkler head belongs to which sprinkler valve

vii. sprinkler booster connections shall be provided and located to allow ready access for the fire brigade

viii. sprinklers need not be provided on the underside of mall roofs if the distance between the closest floor on which combustibles are located and the sprinklered roof exceeds 10 m. Other strategies shall be developed with respect to the control of fire within the mall itself

   Note: *this may require the control of materials (e.g. fire-retarded decorations), limiting the quantities of combustibles (the combustibles within a concession), and requiring a minimum spacing between concessions. Alternatively, sprinklers may be provided to concessions.*

Design Strategies

To minimise the number of occupants put at risk by a fire.

To allow safe egress of occupants put at risk by a fire.

To provide an adequate level of safety for fire brigade.

Design Principles

The building shall be designed so that:

i. there is little risk of spread of fire from the area or enclosure of fire origin

ii. the risk of fire spread from an area or enclosure to another area, enclosure or egress path is not such that the safe egress of occupants having to evacuate is threatened

Details

The following elements shall be designed to maintain insulation, integrity and structural adequacy, as appropriate, when subject to the relevant design fires:

- columns
- beams
- floors (away from deliberate openings)
- loadbearing walls
- walls around cinemas
- stair shafts

Note: *Where voids are deliberately provided in floors (e.g. department stores and malls), insulation and integrity are not relevant at these locations. However, away from these locations it is important to prevent spread of fire to the next level.*

Building elements within the carparks shall be designed in accordance with the Alternative Solutions given in [22] if composite or steel construction or Section C of the BCA, if otherwise.

Ceiling space barriers should be provided to slow the spread of fire within the ceiling space. These should be provided at boundaries between major stores and other areas, between groups of specialty stores (e.g. every 10th store), and at sprinkler zone boundaries.

Methodology

Fire Resistance

The fire resistance of a member may be determined using the following procedure:

i. Obtain or estimate the time-temperature relationship for the relevant design fire or appropriate non-sprinklered fire. This may be based upon test data or calculation. In the case of a sprinklered fire, the air temperature within the vicinity of the structural member may be taken as less than 200°C.

ii. Identify the relevant design criteria for the member—i.e. insulation, integrity and structural adequacy. If the member is loadbearing then it will be necessary to demonstrate structural adequacy. However, if the member is either a wall or a floor slab it may also be necessary to consider integrity and thermal insulation.

iii. Estimate, using a transient heat-flow analysis, the temperatures throughout the member including unexposed surface temperatures if thermal insulation is a relevant criterion.

iv. Determine the load on the member (if any). The level of load applied to the member in the fire situation is defined by AS 1170.1 [23] as:

$$w_f = 1.1G + 0.4Q$$

where G is the dead load and Q the live load.

v. Undertake appropriate structural analysis of the member if loadbearing. Analysis of the structural member will need to take into account the effect of temperature on the mechanical properties of structural steel, reinforcing and prestressing steel, and concrete. In this regard the properties given in AS 4100 [24] and AS 3600 [25] may be used. The normal assumptions of structural mechanics may be considered to apply in the analysis.

vi. Check compliance with design criteria for the relevant time of exposure.

Deemed-to-satisfy Solutions

For a building which has been constructed in accordance with the other provisions of this publication, and incorporates composite or concrete floors and steel or concrete beams and columns, the following solutions can be considered to satisfy the requirements of this section.

Building Element	Steel or Composite Construction	Other Construction
columns (upper two levels)	ESA/M ≤ 30 m^2/tonne	60/-/-
columns (supporting two or more levels)	30/-/- or 25 mm fire-resistant cladding up to the underside of beams	60/-/-
beams	ESA/M ≤ 30 m^2/tonne	60/-/-
floor slabs	60/60/60	60/60/60
loadbearing walls	60/60/60	60/60/60
cinema walls	60/60/60	60/60/60
stair shafts	60/60/60	60/60/60

Ceiling space barriers may consist of a continuation of the wall construction below the ceiling and be of similar construction (eg. plasterboard linings on either side of a steel stud). As the barriers are to act primarily as a radiation shield, it is not necessary to fire-stop gaps around the perimeter of non-combustible services penetrating the barrier. However, it is recommended that the gaps around penetrating services should not exceed 50mm at any location.

BRIGADE COMMUNICATION AND RESPONSE

Design Strategy

To provide sufficient notification and means of fire fighting for the fire brigade.

Design Principles

i. Sufficient means of notification of a fire shall be provided.

ii. Sufficient means of access to the relevant part of the building shall be provided.

iii. Sufficient communication within the building shall be provided.

iv. Sufficient fire brigade access shall be provided.

v. Sufficient hydrants shall be provided and suitably located to facilitate brigade fire fighting.

Notes on Design Principles

The fire brigade's charter relates not only to safety of the occupants of the building but also to the protection of property—including the building in which the fire originates. They are not expected, however, to take unnecessary risks.

The fire brigade is an important part of the fire-safety system, and in relation to the buildings which form the subject of this publication, may be considered to have the following specific functions, in the event of a building alarm:

i. where there is no other evidence of fire, investigate the situation and the probable cause of the alarm

ii. extinguish fires that are small or that are being controlled by the occupants or the sprinkler system—this action will prevent re-ignition

iii. assist with the evacuation of the occupants in the event of a significant fire

iv. undertake any reasonable measures to control, and finally extinguish, a significant unsprinklered fire

v. limit fire spread to other parts of the building

The steps required for successful intervention must be based on the fire brigade intervention model [26].

Details

Hydrants

Hydrants shall be provided generally in accordance with the requirements of AS 2419.1 [22] and each part of the building shall be able to be reached from an external or internal hydrant.

An internal hydrant need only be provided where water cannot be delivered efficiently from an appliance or external hydrant, taking into account the likely direction of attack. Efficient delivery of water is dependent on the number of lengths of hose line that must be laid, and the height above an external hydrant/appliance. It is considered that the limiting number of lengths of hose line that may be laid from an external hydrant or appliance is two (60 m), and the limiting height (beyond which it will be difficult to drag hose lines) is two storeys above the external hydrant/appliance location. The length of the hose stream may be taken as 10 m in accordance with AS 2419.1.

Spacing of internal hydrants shall be based on the assumption that one length of hose line (30 m) only can be laid from each hydrant. In this case the length of the hose stream may be taken as 6 m.

The water supply shall have adequate flow and pressure characteristics and any occasional isolation shall be properly managed (see section on *Management for Fire Safety*).

Fire Indicator Panel

Fire Indicator Panels (FIP's) should be designed and located so that the fire brigade will be called to the closest entrance to the fire. This is important to minimise the response time for the fire brigade.

MANAGEMENT OF FIRE SAFETY

Sound management of fire safety is essential. This can be facilitated by a fire-safety management plan which should have the following objectives:

- minimise the number of fire starts
- extinguish any fire before it becomes threatening
- enable occupants to escape the effects of a fire

These objectives are necessary since shopping centre buildings are designed for limited fire scenarios and the effectiveness of the designed fire-safety systems will always be less than 100%.

Responsibilities of Building Owners and Occupiers

Shopping centre owners and occupiers have the responsibility of ensuring the safety of all building occupants, including any member of the public entering the premises. That this is the case is reinforced by various legal requirements.

In order to safeguard the occupants from fire injuries, a sound fire-safety management plan must be developed and implemented. Such a plan can only be successfully developed and implemented if it receives full support from all management levels of the centre, in particular the senior management. The organisation within a shopping centre likely to be given the responsibility to develop and implement a plan is Centre Management or its designate; but for major stores (including department stores) it is likely that the management plans for all stores of a particular chain will have been developed by a centralised group but implemented locally. It is nevertheless essential that management plans for major stores are consistent with those of Centre Management.

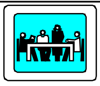
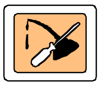
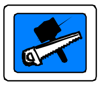
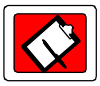
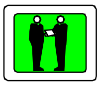
Fire-safety Management Plan

Having established the objectives of the fire-safety management plan it is necessary to develop the plan. This plan should be developed by reference to HB 143 [28] and AS/NZS 4360 since managing fire safety is really managing the risks associated with potential fires. The process that should be used in this regard is illustrated in flowchart shown on the right.

The plan shall be documented and communicated to staff. The successful implementation of the fire-safety management plan requires ongoing communication, consultation and review especially with those who will be involved in implementing the plan.

Fire-safety management tasks

Application of the above process to shopping centre situations has resulted in the identification of many fire-safety management tasks. These are given in Table 1. These are tasks which are likely to be important but no attempt has been made to rank them in order of priority. It will be noted that each of these tasks can be considered as involving a particular type of action:

Types of Actions			
1		➨	*Communication of issues and procedures*
2		➨	*Maintenance*
3		➨	*Refurbishment*
4		➨	*Auditing*
5		➨	*Reinforcement*
6		➨	*Training*

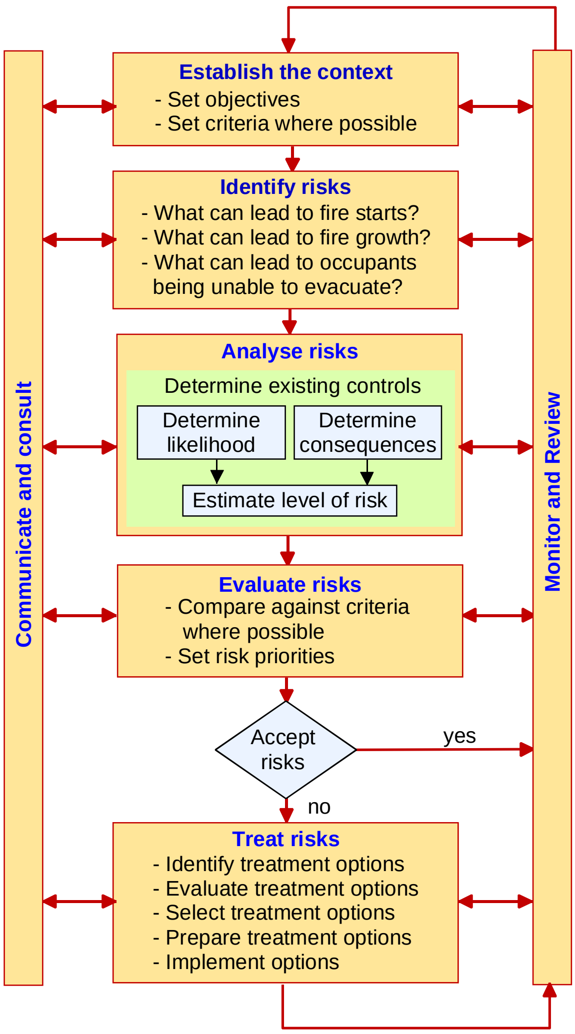


Table 1 Summary of Management Tasks

MINIMISING FIRE STARTS

Development and communication of rules regarding storage of combustibles

(a) rules need to be developed and documented with respect to:

- no storage within SOU ceilings
- no storage close to switchboards and other electrical/mechanical equipment
- penalties for non-compliance

(b) rules need to be well communicated with photographs showing acceptable and unacceptable situations.

Routine maintenance of equipment

Maintenance of electrical and mechanical equipment aimed at reducing likelihood of overheating or electrical faults and consequent fires. Maintenance actions shall be documented and filed for easy recall.

Establish and communicate "hot work" procedures

These procedures must be documented and communicated. All workers undertaking cutting, welding, or other hot work must:

- remove or cover combustibles below or adjacent to the hot working area
- carry a functional portable extinguisher
- be trained in the use of extinguishers
- "sign on" before work is started and "sign off" after completion
- understand penalties for non compliance

Ongoing upgrade of electrical lighting and wiring

Older higher voltage lighting and older wiring may represent significant sources for fire initiation. Modifications shall be documented and filed for easy recall.

Routine inspections of storage of combustibles in relation to potential heat sources such as switchboards and mechanical equipment

Storage of goods in close proximity to electrical and mechanical equipment can lead to overheating and fire initiation. These audits shall be documented and filed for easy recall.

Audits of "hot spots" in switchboards and equipment

Can be accomplished using thermal imaging cameras. These audits shall be documented and filed for easy recall.

Rectification of hot spots

Incorporated as part of maintenance program. Rectification actions shall be documented.

Policing of penalties for non-compliance with procedures

This is where the contractor or tenant is warned or penalised for violations. Constant education showing the ease with which a fire can start, and the potential consequences, is required as part of staff and contractor training. A record shall be kept of non-compliances.

EARLY DETECTION

Establish and communicate who should be notified in the event of a member of staff observing a fire start or smoke

This will most likely be centre management/security staff. Need to also establish how such notification is to be made.

Establish and communicate who should investigate a potential incident should a smoke or other detector be activated

Maintenance of automatic fire detection and alarm equipment

This is concerned with the operability of FIP's and associated automatic detection systems such as smoke detectors.

Relevant standard: AS 1851.8 including Supplement 1 [29].

Use of security cameras and security staff training

Most areas of major shopping centres are visually monitored to reduce theft. Security staff need to be able to recognise a fire start and respond in the accordance with established procedures.

General staff training

Similarly a wide range of staff should be trained to recognise a fire start and respond in the accordance with established procedures.

Table 1 Summary of Management Tasks (cont'd)

EARLY SUPPRESSION

Establish and communicate whose responsibility it is to fight a fire with an extinguisher
The rule should generally be that the closest trained staff member to the detected fire should seek to extinguish the fire with an extinguisher.

Establish and communicate when it is appropriate for security/centre management staff to use a hose reel
It is not expected that general shop staff will use a hose reel.

Maintenance of portable extinguishers
Relevant standard: AS 1851.1 [30].

Maintenance of hose reels
Relevant standard: AS 1851.2 [31].

Training of general staff in the use of portable extinguishers
Required

Training of security staff in the use of hose reels and extinguishers
Required

LATER SUPPRESSION

Establish and communicate whose responsibility it is to communicate and interact with the fire brigade before and after it arrives
The initial contact will probably be made by security/centre management at the time that a fire is reported. Security/centre management likely to be responsible throughout.

Assist fire brigade to fire source
The purpose of this is to ensure that the brigade gets to the fire as quickly as possible.

Maintenance of sprinkler pumps and other parts of sprinkler systems
Relevant standard(s): AS 1851.3 [32], AS 1951.14 [33].

Maintenance of hydrant systems and hydrant pumps, if any
Relevant standard(s): AS 1851.14, AS 1851.4 [34].

Establish and communicate policy with respect to storage of combustibles in relation to sprinkler heads
The aim is to:

- limit the shielding due to stored combustibles and non-combustibles in order to maximise sprinkler effectiveness
- explain the consequences of not complying
- establish and communicate penalties for non-compliance

Auditing of combustibles and non-combustibles in relation to sprinkler heads
Aim is to provide a mechanism to measure and reinforce compliance with above policy so as to ensure that sprinklers are not overrun due to late activation or to water not being able to get to fire.

Establish and communicate policy with respect to sprinkler isolation
The aim is to:

- minimise the time that sprinklers are isolated – encourage construction procedures that only require short term isolation
- ensure that isolation procedures do not introduce permanent blockages into pipework
- ensure that sprinkler system is reinstated each day or at the completion of work whichever is the lesser period of time
- ensure that sprinkler modifications are adequately recorded such that there is no confusion about which sprinkler belongs to which zone
- enforce penalties for non-compliance

Policing of penalties for non-compliance with procedures
This is where the contractor or tenant is warned or penalised for violations. Constant education showing the importance of sprinklers and the effects of high levels of shielding is required as part of staff and contractor training.

Table 1 Summary of Management Tasks (cont'd)

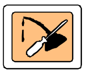
EFFECTIVE EVACUATION

Development and communication of evacuation plan

See Table 2 below

Maintenance of doors to stairs enclosures

Relevant standard: AS 1851.7 [35]

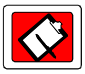


Maintenance of smoke control systems

This is concerned with ensuring the correct operation, in the event of a fire, of:

- fans
- dampers
- ensure that egress paths are kept tenable

Relevant standard(s): AS 1851.6 [36]



Auditing of combustibles in exit paths

This is concerned with ensuring that:

- no combustibles in exits, corridors or stairs
- exit paths are free of obstacles

Policing of rule for no combustibles in exits

- no storage within exits, corridors or stairs

Practice and training in relation to evacuation plan

It is important that staff have an awareness of their responsibilities and that this is reinforced by training and practice.

Evacuation of parts of the shopping centre may be required. To be successful, this must be conducted in an orderly and timely manner and in such a way to *reinforce* the exits likely to be chosen by the occupants. An evacuation plan is therefore essential and the principles given in AS 3745 [37] should be consulted when developing the plan. Table 2 below is intended to help with the development of such a plan by highlighting some of the key factors that need to be considered by the Emergency Planning Committee (EPC). The Emergency Control Organisation (ECO) established by the EPC must have the support of senior management and be authorised to take "control" of a building during emergencies, i.e. instructions given by ECO personnel should overrule normal management structure during emergencies.

In a shopping centre the ECO will be composed of staff from various parts and organisations within the centre including Centre Management. The make-up of the ECO will be decided by the EPC which must have senior staff representatives. Suggestions on the responsibilities of wardens is given in Table 3.

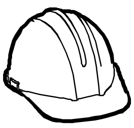
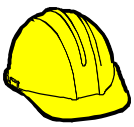
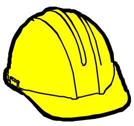
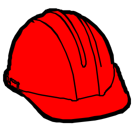
Table 2 Evacuation Plan—Key Factors

Key Factor	Action Required	Notes
Fire Situations	Identify the key potential fire situations.	Characterised by fire location and severity, number and type of occupants, potential direction of smoke spread, and exit arrangement.
Wardens	Appoint the ECO personnel—the chief warden, deputy chief warden, communication officer, area wardens and wardens.	The ECO structure will be established by the EPC (See Table 3 for suggested responsibilities of wardens).
Fire Brigade	Communicate with fire brigade before and after arrival on site.	Persons responsible should be clearly defined, and trained in procedures.
Egress Paths	Determine which egress paths are likely to be used; and how mobility-impaired persons be evacuated.	A function of the fire situation; which escalators should be stopped and which should be continued, reversed, etc.
Evacuation Extent	Determine the extent of evacuation required.	A function of the fire situation. As a general rule, evacuation of other than the immediate fire-effected area will not be necessary if the fire has been extinguished before sprinkler activation or the sprinklers have activated within a specialty shop.

Table 2 Evacuation Plan—Key Factors (cont'd)

Key Factor	Action Required	Notes
Evacuation Advice	Determine the best way to communicate with persons in the part of the building that must be evacuated; also what should be stated if voice instructions are given.	Voice instructions should be specific to the situation and are seen as essential. They must be pre-planned (as much as possible) and practiced.
Evacuation Assistance	Determine who will assist in providing physical direction and who will provide assistance to those with mobility impairment.	These aspects should be planned and practiced.

Table 3 Suggested Responsibilities of Wardens

Type of Warden	Responsibilities
Chief Warden (or Deputy) 	• ensure that evacuation plans exists for all major stores, department stores and cinema complex • understand evacuation plans • decision to evacuate any part of mall* • decision to use PA instructions within mall • coordinate evacuation with area wardens associated with major stores, department stores and cinema complexes • instruct Area Wardens within mall • authority over other Wardens
***Area Wardens** – major stores, department stores; cinema complexes* 	• understand evacuation plans • decision to evacuate store or cinema complex • coordinate evacuation with Chief Warden • instruct other Wardens within store/cinema complex
***Area Wardens** – mall* 	• understand evacuation plans • assist with escalator management, if appropriate • assist with directing evacuees from mall/specialty shops • coordinate evacuation with Chief Warden
Wardens 	• understand evacuation plans • assist with directing evacuees subject to instructions from relevant Area Warden • coordinate evacuation with Area Warden

* mall refers to all of the shops excluding majors which have own Warden and evacuation plan

CONCLUSIONS

This publication gives design principles and details which address the fire-safety objectives of the BCA. By implication, the performance requirements of the BCA are also considered. The design approach described herein will lead to greater flexibility and economy of construction—and in many situations, a greater level of safety. Sructural steel with little or no fire protection can be used in these buildings and offers advantages with respect to speed of construction, reduced costs, and flexibility for future building modifications.

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APPENDIX 1 Example

Introduction

The purpose of this example is to illustrate aspects of design and management described previously in this publication.

Design is normally an iterative process whereby building characteristics are assumed and then tested to see if the proposed details will perform satisfactorily when evaluated against the design criteria. There are some matters such as the fire-resistance of the structural members that can be directly specified from this design publication and for which no iteration is required. However, smoke management is an example of one aspect for which design is likely to be iterative.

Aspects of the evacuation plan are also presented in order to reinforce some of the issues raised in the previous section.

For the purpose of this example only limited fire scenarios are considered.

Building Description

General Features

The proposed shopping centre is shown in Figure A1 and represents an advanced stage of design.

The building consists of a three level shopping mall incorporating specialty shops and major stores with a five level (rise-in-storeys of 4) department store at the West end. At the East end is a fresh food market.

Access to Levels 2 - 4 of the department store and Levels 2 and 3 of the mall is available directly from adjacent carpark levels. Street level access is available at Level 2. Direct access between the department store and the mall is available at Levels 2, 3 and 4. Level 3 incorporates specialty shops and a cinema complex. The floor-to-floor heights between levels are typically 5 m.

Openings have been incorporated in the floors of the mall at levels 2 and 3 to increase the ambiance. The void locations and areas comply with the recommendations given in the section *Smoke Development and Management*. An attempt has been made to ensure that the location of exits and the total exit width, associated with any location, comply with the recommendations given in the section *Occupant Avoidance*.

Movement between the levels is achieved by a combination of stairs and escalators/travelators. These are indicated on Figure A1.

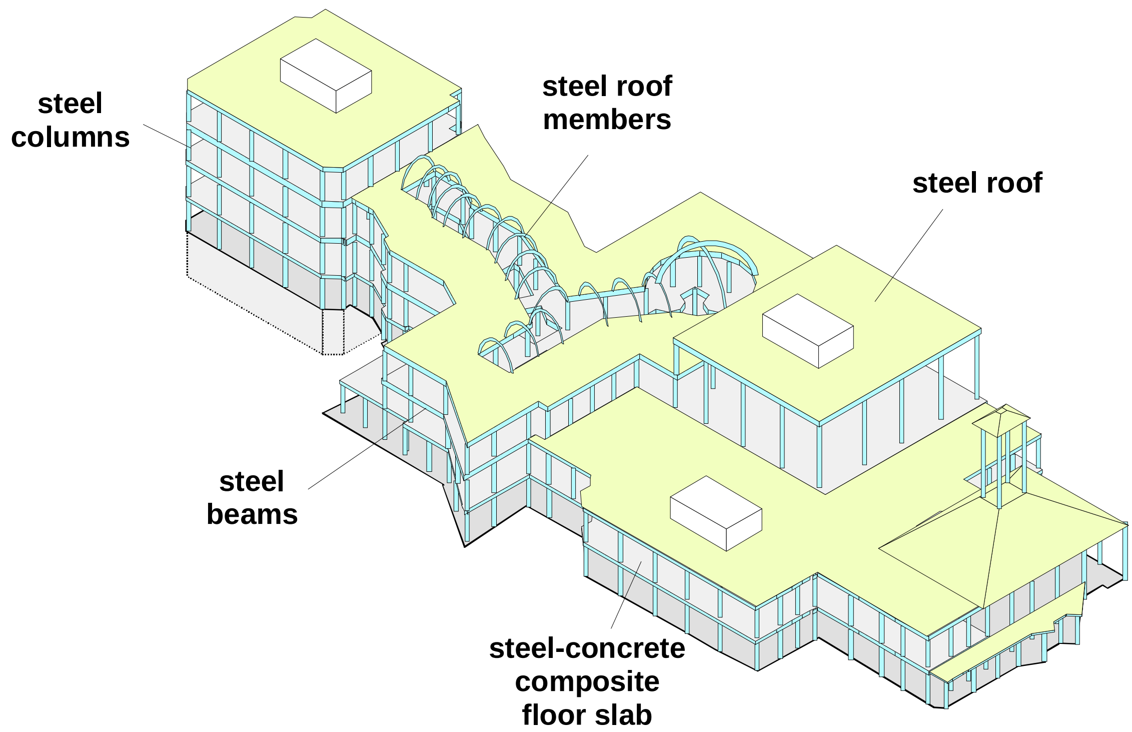
Form of Construction

Due to the need to minimise construction time and reduce costs, the centre will be constructed using a structural steel frame. The shopping centre, including the carparks, will be built using steel columns and composite floors. The roof will also be steel construction.

A schematic view of the construction showing the steel framing is given below. The carparks are not shown in this figure.

The proposed construction complies with the recommendations of the section *Flame Spread and Management*.

The building incorporates a high roof over the food court and the fresh food market. A glazed barrel roof is provided over the top of the other parts of the mall at the uppermost level.



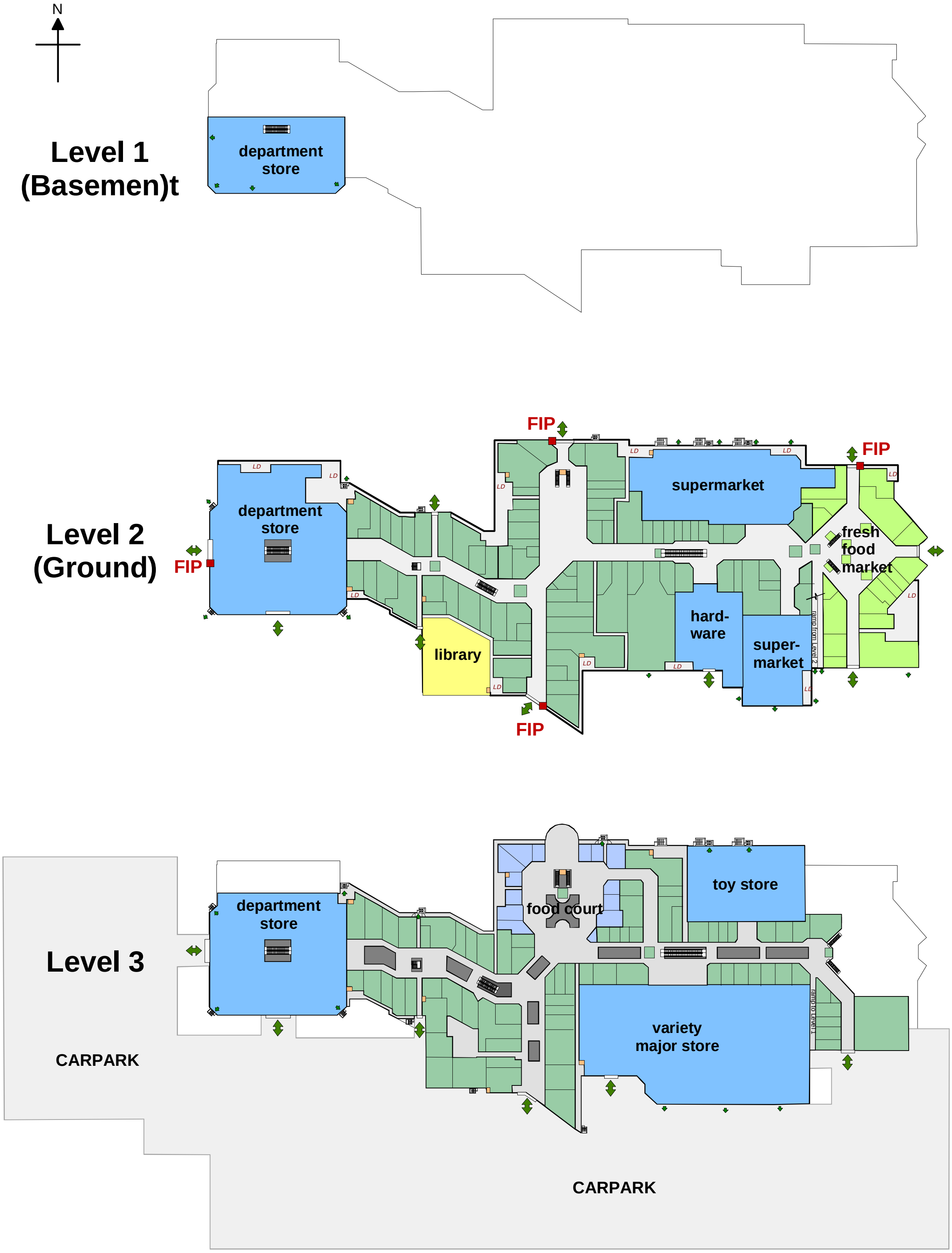

N
Level 1
(Basemen)t
department store
FIP
department store
Level 2
(Ground)
FIP
FIP
supermarket
fresh food market
FIP
library
hard-ware
super-market
Level 3
department store
food court
toy store
variety major store
CARPARK
CARPARK

Figure A1

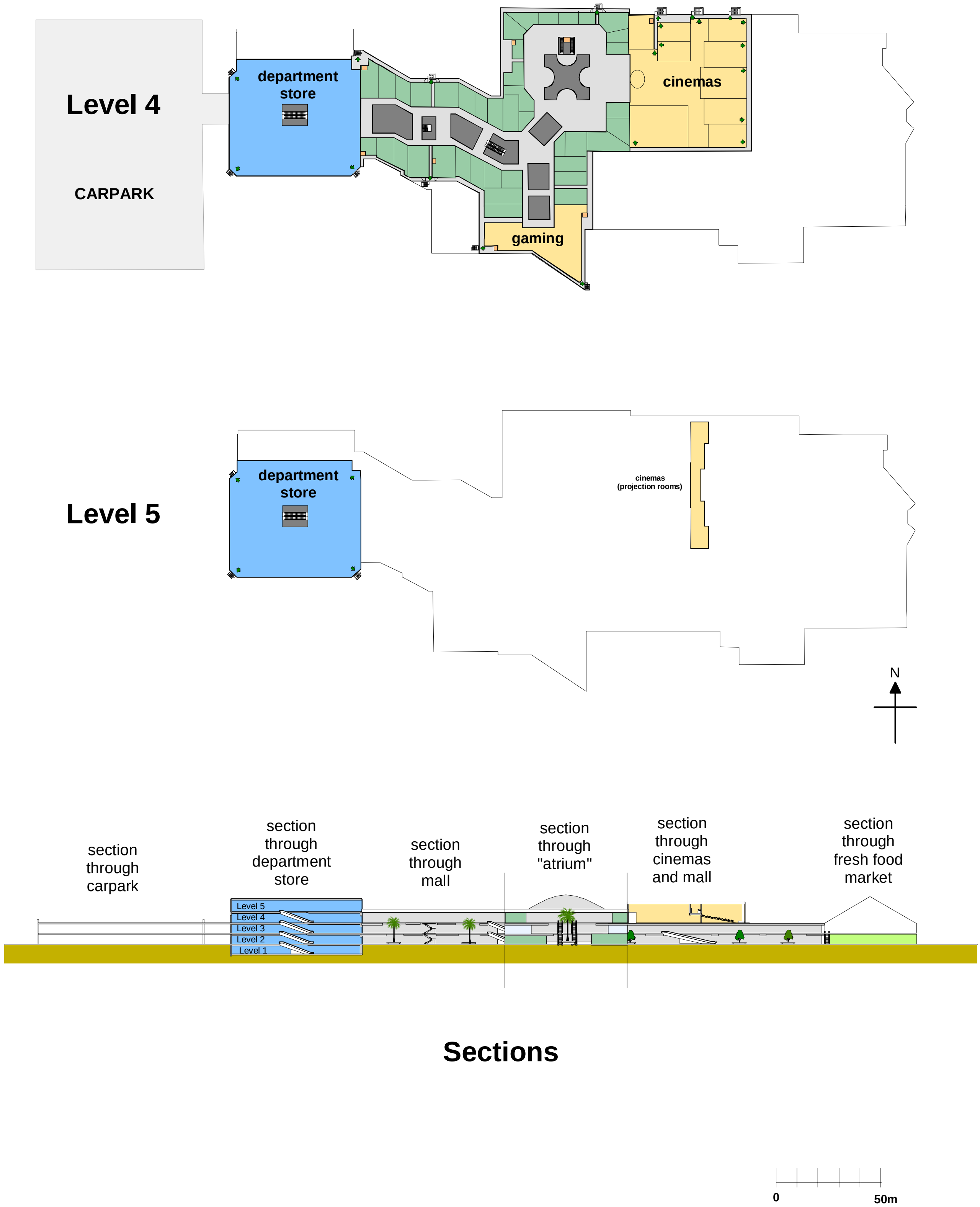

Level 4
CARPARK
department store
cinemas
gaming
Level 5
department store
cinemas (projection rooms)
N
section through carpark
section through department store
section through mall
section through "atrium"
section through cinemas and mall
section through fresh food market
Level 5
Level 4
Level 3
Level 2
Level 1
Sections
0
50m

Figure A1

Means of Egress

The potential means of egress from each level or store to outside or to carpark levels are shown (green arrows) in Figure A1. The *spacing* of exits from the mall *does not* comply with BCA requirements.

It should be noted that the cinemas have independent exits such that it is not necessary to evacuate into the mall. This will be discussed later. Throughout the shopping centre there are a large number of service corridors which link loading docks to various parts of the centre, enabling the delivery of goods to various parts of the centre. Access into the rear of shops from these corridors is common to allow direct delivery. It is noted that in some shopping centres these corridors are used as tunnels for emergency egress (although not permitted by the BCA). This is not the case with the proposed design where "fire" tunnels from the mall are not provided as they are unlikely to be used.

Some of the specialty shops around the perimeter of the centre open directly to outside or to a carpark level as well as into the mall. In the case of major stores access directly to outside, or to a carpark level, is available in some situations as well as into the mall.

Fire-safety Hardware

Smoke detection, portable extinguishers, hose reels, sprinklers, and hydrants will be provided in accordance with the section *Detection and Suppression*. The centre will incorporate numerous sprinkler zones in order to minimise the area that is isolated.

The challenge with shopping centres is to get the fire brigade to the incident as quickly as possible. Following the recommendations in the section *Fire Brigade Communication and Response*, FIP's are located at the major entrances to Level 1 such that these give specific guidance on the approximate location of the fire within the building (see also Figure A1).

Smoke Control Aspects

Each major store (stores with an area of greater than 1000 m^2) has an automatic smoke exhaust system. In the case of the department store, a smoke exhaust system is to be provided on each level to allow extraction of smoke should a fire develop.

Extraction fans are provided in the roofs above the food court and fresh food market areas. Smoke exhaust fans are provided along the barrel roof of the mall.

In the major stores where there is tall racking the sprinkler heads are located between the racks in order to minimise shielding effects and the height and materials within the racking have to be limited to ensure that the sprinkler system is commensurate with the hazard. It may also be necessary to utilise a sprinkler system of greater capacity than Ordinary Hazard III.

Aspects such as the provision of baffles and smoke reservoirs are considered in more detail below.

Fire Scenarios

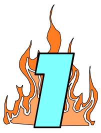
It can be assumed that the shopping centre being considered in this example is designed and managed such that the risk level associated with a C3 fire has been reduced to a low enough level by reducing the probability of its occurrence. A C3 design fire is therefore not adopted.

The following scenarios are considered for the purpose of this example. The scenarios chosen are not exhaustive and fires in the other major stores and on other levels would, in practice, need to be considered.

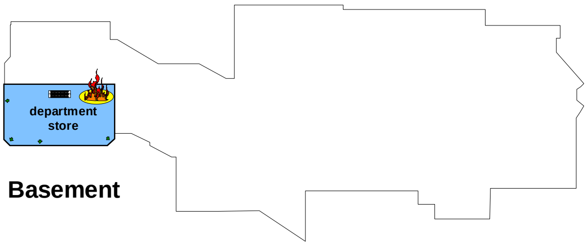
Fire Scenario	Comments
1 *fire in department store (Level 1)*	• occupied hours • fire in storage area at edge of store • sprinklers activate • occupant fire fighting not undertaken
2 *fire in supermarket (Level 2)*	• occupied hours • fire in storage area at rear of store • rear exits cannot be used • sprinklers activate
3 *fire in major toy store (Level 3)*	• occupied hours • fire occurs at centre of store in one of racks • sprinklers activate
4 *fire in fresh food market (Level 2)*	• occupied hours • fire associated with a non-sprinklered concession • fast growing fire • fire is extinguished by the fire brigade
5 *fire in specialty shop (Level 2)*	• occupied hours • fire in a variety shop • fast growing fire • sprinklers activate
6 *fire in area outside cinemas (Level 4)*	• outside normal trading hours • shopping centre mostly not occupied at the time of the fire • cinemas occupied • sprinklers activate

Consideration of Fire Scenarios

Aspects of occupant avoidance, smoke management, and the evacuation plan will now be considered for each of the above scenarios.



FIRE IN DEPARTMENT STORE (BASEMENT - LEVEL 1)



Smoke Management

The volume of smoke generated from a sprinklered fire is very dependent on the level of shielding. In this case it can be assumed that the positions of the sprinkler heads and racks has been specified such that the sprinkler heads are located between the storage racks so that a C2-2 fire can be assumed.

A ceiling is incorporated throughout the department store but not in the storage area. The basement has a floor plan area of 2500 m^2. The storage area has a plan area of 300 m^2 and is linked to the rest of the basement level via two 2.5 m high x 1.5 m wide doors. There is no direct connection into the ceiling space in the rest of the basement.

The basement level is connected to the other upper levels via an escalator shaft. A baffle is provided around this shaft to prevent the flow of smoke up the shaft to the levels above. This baffle is 750 mm in depth. A bulkhead above the lift doors and the stair doors is provided to give at least 750 mm of separation between the ceiling and the top of the doors.

The volume of smoke that can be stored within the storage area prior to smoke being emitted from the doors is (5-2.5) x 300 = 750 m^3. The reservoir available *below* the ceiling within the remainder of the basement is 2200 x 0.75 = 1650 m^3.

Utilising the equations for smoke volume given in [9] (in the absence of better information), the relationship between volume of smoke and time can be taken as:

$$V = 3000\,(1 - e^{-t/240})$$

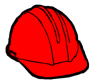
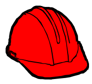
The time in the above formula corresponds to the time from which the fire begins to grow rapidly. The time for sprinkler activation can be taken as 60 s beyond this time.

The total available reservoir is therefore 750 + 1650 = 2400 m^3. According to the above equation, this will be exceeded after about 6 minutes. If smoke is to be prevented from going up the escalator shaft then the smoke extraction system must operate much earlier than this. However, a high level of extraction is not required. Assuming that the smoke extraction system is activated once a sprinkler head is broken and that it takes 60 s for the system to build up to its capacity, then a system capable of extracting 5 m^3/s would extract 5 x 60 x 5 = 1500 m^3 after 6 minutes. This would prevent spillage into the escalator shaft and into the stairs or lifts.

The above calculations demonstrate the importance of ensuring a relatively non-shielded sprinklered fire.

Aspects of Evacuation Plan

Although the smoke layer will be sufficiently high it will be necessary to evacuate occupants. It is assumed that all Wardens will act in accordance with the Evacuation Plan including the following actions:

Person	Action	Timing
Warden  *(Level 1)*	• contacts Area Warden • makes decision to evacuate • decides which stairs to be used • ensures staff are assisting occupants • ensures staff assist disabled occupants with escalator upwards moving or lift	
Area Warden  *(Dept. store)*	• contacts Chief Warden • communicates with Level 1 Warden • ensures that all occupants and staff have left Levels 1 and 2	
Warden  *(Dept. store – Level 2)*	• decided to evacuate Level 1 into mall or to outside • stops downwards moving escalator; possibly reverses direction once clear • checks that all occupants and staff have left Level 2	
Chief Warden 	• communicates with fire brigade • decides whether other parts of centre should be evacuated—in this case not necessary	

Occupant Avoidance

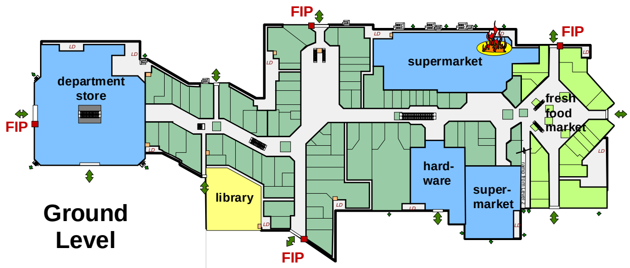
The basement has no way out except for the stairs, escalator and lift. The lifts and possibly the escalators may be used to evacuate persons with mobility disabilities, but the stairs will have to be used for other occupants. There are four stairs providing an aggregate exit width of 6m from the basement. Assuming that all exits are available the time for movement of occupants is calculated using the simplified equations given in [9]

Assume that each exit has a door width of 1500 mm. Number of occupants is taken as 2000 ÷ 6 = 333 persons

queuing time = 333 ÷ (1 x 1.2 x 4) = 69 s.

Travel time is much less that this and therefore does not govern. It is concluded that evacuation of the basement can occur very quickly.

FIRE IN SUPERMARKET (LEVEL 2)



Smoke Management

In this case the fire is assumed to occur at the rear of the northern supermarket. The distribution of sprinklers and combustibles is such that it is assumed that a C2-3 sprinklered fire occurs. The doors into the mall are 2.5 m high with a 2.3 m bulkhead above them. As there is no ceiling in this particular store, the total reservoir available for storing smoke is 2500 x 2.3 = 5750 m^3. This reservoir, in association with a smoke extraction system, will ensure that the smoke does not enter the mall. An extraction rate of 5 m^3/s is all that is required. If however, it is possible that a heavily shielded fire (e.g. C2-4 fire) could occur in the storage area then almost twice as much smoke will be produced. In that case the extraction rate will need to be higher to prevent smoke entering the mall. The capacity in this situation is estimated as follows:

Time at which 5750 m^3 of smoke is produced = 160 s.

Assuming that the exhaust fans activate upon sprinkler activation (60 s) and that it takes 60 s to come up to speed, the volume of smoke generated at this stage will be 4720 m^3 and it will be necessary for the extraction system to exhaust the remaining smoke. The rate of smoke volume is given by:

$$\frac{dV}{dt} = \frac{k_c}{60} e^{-t/240}$$

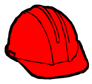
where k_c = 3000 in this case

At 120 s, the rate is 30 m^3/s. This extraction rate is required if smoke is not to enter the mall.

This calculation serves to demonstrate the importance of not having severely shielded sprinklers.

Aspects of Evacuation Plan

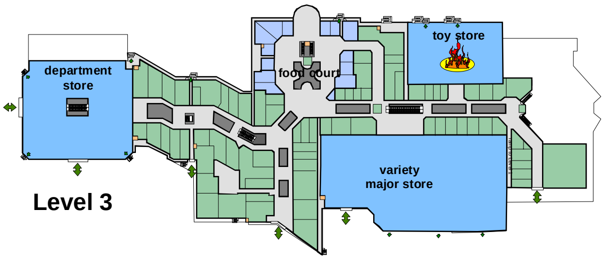
Although the smoke layer will be sufficiently high it will be necessary to evacuate occupants. It is assumed that all Wardens will act in accordance with the Evacuation Plan including the following actions:

Person	Action	Timing
Area Warden  *(super-market)*	• contacts Chief Warden • decides to evacuate • decides which exits are to be used • ensures staff are assisting occupants • ensures that all occupants and staff have left store	
Warden  *(super-market)*	• communicates with Area Warden • check that all occupants and staff have left store	
Chief Warden 	• communicates with fire brigade • decides whether other parts of centre should be evacuated—in this case, unlikely to be necessary.	

Occupant Avoidance

The supermarket has exits at the rear (emergency exits) and at the front. There are no emergency exits at the side as travel distance is not seen as a significant issue. It is assumed that the rear exits will be inaccessible and that the occupants will evacuate into the mall. Given that there could be 380 occupants and that the aggregate effective width at the front entrance is 4m it follows that there will be 380 ÷ (1.3 x 4) = 73 s of queuing. This assumes that all occupants are waiting at the entrance and can leave without security checks. Assuming that the occupants closest to the fire (i.e. at the rear of the store) are the first to move, it will take them 90 ÷ 1.2 = 75 s to reach the entrance. The 90 m travel distance allows for orthogonal movement around the aisles. The above estimated queuing time is not correct as some of the occupants will have passed through the entrance by the time that other arrive. However, it can be seen that evacuation can be achieved within 3 minutes. It is to understand that, in the event of an emergency, evacuation must proceed irrespective of any financial transaction being undertaken.

FIRE IN MAJOR TOY STORE (LEVEL 3)



Smoke Management

In this case the fire is assumed to occur at the centre of the store in a tall rack and is probably associated with an electrical short circuit. The total floor area of the store is 1700 m^2 and there is no ceiling. The racks are tall reaching to within 1m of the sprinkler heads which have been specifically located between the aisles to minimise shielding. It is assumed that a C2-3 fire is appropriate. The height of the doors at the front of the store is 2.5 m and this gives a reservoir of 2.4 m above the door. The total reservoir available for holding smoke is 1700 x 2.4 = 4080 m^3. This reservoir in association with a smoke extraction system will ensure that the smoke does not enter the mall.

Considering that the sprinklers activate after 60 s, and that it takes another 60 s for the fans to achieve their capacity, the volume of smoke produced by this stage is 2360 m^3. The rate at which smoke is produced is given by:

$$\frac{dV}{dt} = \frac{k_c}{60} e^{-t/240}$$

where k_c = 1500 in this case

At 120 s, the rate is 15 m^3/s. An extraction rate similar to this value would be required if smoke is not to pour out into the mall.

This calculation serves to demonstrate the importance of not severely shielded sprinklers and the level of confidence that is required of sprinklers to handle such a fire effectively.

Aspects of Evacuation Plan

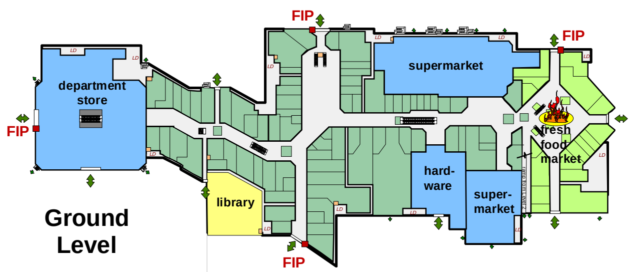
Again, although the smoke layer will be sufficiently high, it will be necessary to evacuate occupants. It is assumed that all Wardens will act in accordance with the Evacuation Plan including the following actions:

Person	Action	Timing
Area Warden *(major toy store)*	• contacts Chief Warden • decides to evacuate • decides which exits are to be used • ensures staff are assisting occupants • ensures that all occupants and staff have left store	
Warden *(major toy store)*	• communicates with Area Warden • check that all occupants and staff have left store	
Chief Warden	• communicates with fire brigade • decides whether other parts of centre should be evacuated—in this case, not likely to be necessary	

Occupant Avoidance

The toy store has exits at the rear and a front entrance. Even though the fire is at the centre of the store, it is most likely that the occupants would leave by the entrance into the mall. Including the register passageways, there is a total effective width available of 8 m. Given that there are 255 occupants the store can be evacuated within 3 minutes.

FIRE IN FRESH FOOD MARKET (LEVEL 2)

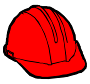


Smoke Management

In this situation a non-sprinklered fire associated with a small concession occurs in the fresh food market. This is because no sprinklers have been provided above this particular concession. The food market is covered by a high roof which provides a substantial reservoir. Extraction fans are provided near the apex. Using a zone model to determine the rate of descent of the hot layer and associating this hot layer with smoke, the time at which the smoke layer will drop below the opening into Level 3 can be determined. Even a fire of 5MW will require very substantial extraction due to the height to the roof and the resulting air entrainment. The incorporation of sprinklers above the concession may be necessary to reduce the size of the extraction fans.

Aspects of Evacuation Plan

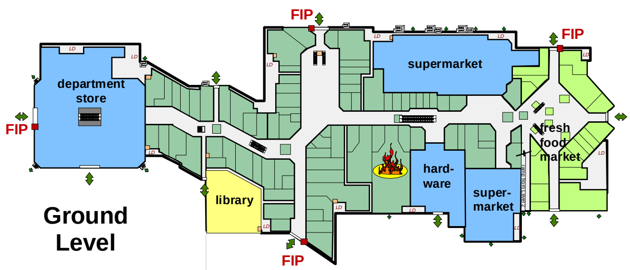
It is assumed that all wardens will act in accordance with the Evacuation Plan including the following actions:

Person	Action	Timing
Area Warden  *(fresh food market)*	• contacts Chief Warden • decides to evacuate along with Chief Warden • decides which exits are to be used • ensures staff are assisting occupants • ensures that all occupants and staff have left area	
Warden  *(fresh food market)*	• communicates with Area Warden • check that all occupants and staff have left area	
Chief Warden 	• communicates with fire brigade • stops downwards moving escalators into this area • decides whether other parts of centre should be evacuated – perhaps Level 3 of mall	

Occupant Avoidance

Due to the volume of the reservoir available there is considerable time available for evacuation and many exit paths.

FIRE IN SPECIALTY SHOP (LEVEL 2)



Smoke Management

A fire in a specialty shop on ground level will send smoke directly into the mall. Fires in the specialty shops will be C2-1 fires and will result in only small quantities of dilute smoke going into the m mall. In some cases where racks of goods are provided the fire may become a C2-2 fire. In that case a substantial quantity of smoke will spill into the mall unless there is a direct opening into the ceiling space in that particular store. Assuming this is not the case, then smoke will distribute along the Level 2 mall and up through the openings into the levels above. This smoke will be also drawn towards the roof by vents provided these are opened in the region of the fire. The earlier that the vents are opened the better.

As the smoke moves through the openings, some of it will spill on to the adjacent levels where it will be mixed and result in some level of obscuration at these levels. However, the model test results suggest that the smoke on these levels will not present a serious threat to the occupants who can move further along the mall.

Aspects of Evacuation Plan

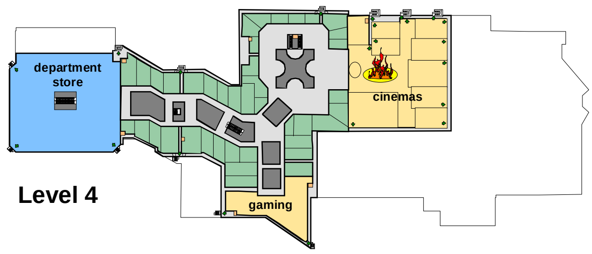
It is assumed that all wardens will act in accordance with the Evacuation Plan including the following actions:

Person	Action	Timing
Chief Warden 	• ensures that roof vents have opened • communicates with fire brigade • stop downwards moving escalators into this area • moves occupants away from this area • monitors smoke at other levels • prepares to move occupants away at the other levels	

Occupant Avoidance

Evacuation should not be necessary.

FIRE IN AREA OUTSIDE CINEMAS (LEVEL 4)

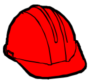


Smoke Management

Smoke from fire will be dealt with by extraction fans at the roof level.

Aspects of Evacuation Plan

It is assumed that all wardens will act in accordance with the Evacuation Plan including the following actions:

Person	Action	Timing
Area Warden  *(cinema complex)*	• contacts Chief Warden • decides to evacuate cinemas along with Chief Warden • moves occupants away from cinema area • ensures staff are assisting occupants • ensures that all occupants have left area and cinemas	
Warden  *(cinema complex)*	• communicates with Area Warden • checks that all occupants and staff have left area and cinemas	
Chief Warden 	• communicates with fire brigade • decides whether other parts of centre should be evacuated	

A means of communication into the cinemas is necessary.

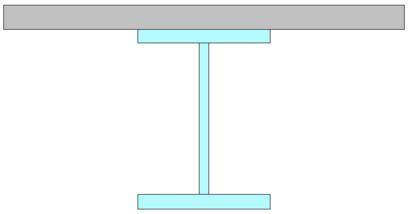
Occupant Avoidance

In this case a fire occurs in the area outside of the cinema and this means that the occupants within the cinemas should be evacuated via the dedicated alternative exits. Occupants will use these exits as there is no alternative.

APPENDIX 2 Exposed Surface Area to Mass Ratio of Steel Sections—k_{sm} (m^2/tonne)

Beams

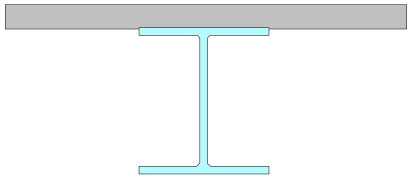
welded-plate sections



section	k_{sm}
1200WB455	8.51
423	9.10
392	9.79
342	10.4
317	11.1
278	12.1
249	12.6
1000WB322	10.0
296	10.8
258	11.8
215	13.4
900WB282	10.7
257	11.7
218	13.0
175	15.3
800WB192	13.1
168	14.5
146	16.5
122	18.9
700WB173	13.0
150	14.3
130	16.3
115	18.4

section	k_{sm}
500WC440	5.41
414	5.78
383	6.21
340	7.30
290	8.51
267	9.22
228	10.7
400WC361	5.48
328	6.11
303	6.56
270	7.34
212	9.25
181	10.7
144	13.4
350WC280	6.08
258	6.54
230	7.30
197	8.49

hot-rolled sections

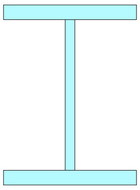


section	k_{sm}
610UB125	14.9
113	16.3
101	18.1
530UB 92.4	17.8
82.0	19.9
460UB 82.1	17.7
74.6	19.4
67.1	21.4
410UB 59.7	21.9
53.7	24.1
360UB 56.7	21.1
50.7	23.4
44.7	26.3
310UB 46.2	23.2
40.4	26.2
250UB 37.3	24.7
31.4	29.0
200UB 29.8	26.3
180UB 22.2	27.1
150UB 18.0	28.3

section	k_{sm}
310UC158	9.66
137	11.0
118	12.7
97	15.3
250UC 89.5	13.9
72.9	16.8
200UC 59.5	16.8
52.2	18.9
46.2	21.2
150UC 37.2	20.3
30.0	24.6

Columns

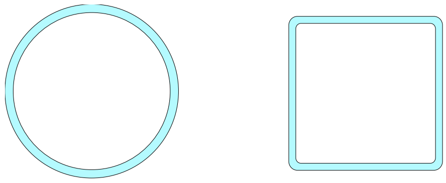
welded-plate sections



section	k_{sm}
1200WB455	9.61
423	10.3
392	11.1
342	11.5
317	12.4
278	13.3
249	13.7
1000WB322	11.2
296	12.1
258	13.1
215	14.8
900WB282	12.1
257	13.3
218	14.6
175	17.0
800WB192	14.7
168	16.1
146	18.4
122	20.9
700WB173	14.5
150	16.0
130	18.3
115	20.6

section	k_{sm}
500WC440	6.55
414	6.99
383	7.52
340	8.77
290	10.2
267	11.1
228	12.9
400WC361	6.59
328	7.33
303	7.88
270	8.82
212	11.1
181	13.0
144	16.1
350WC280	7.33
258	7.89
230	8.82
197	10.3

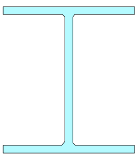
hollow sections



section	k_{sm}
457.0×12.7CHS	10.3
9.5CHS	13.7
6.4CHS	20.2
406.4×12.7CHS	10.4
9.5CHS	13.7
6.4CHS	20.2
355.6×12.7CHS	10.4
9.5CHS	13.8
6.4CHS	20.3
323.9×12.7CHS	10.4
9.5CHS	13.8
6.4CHS	20.3
273.1×9.3CHS	14.2
6.4CHS	20.4
4.8CHS	27.0
219.1×8.2CHS	16.1
6.4CHS	20.5
4.8CHS	27.1
168.3×7.1CHS	18.7
6.4CHS	20.7
4.8CHS	27.3
114.3×6CHS	22.4
4.8CHS	27.7
88.9×5.5CHS	24.7
4.8CHS	28.1

section	k_{sm}
250×250×9.0SHS	14.6
6.0SHS	21.7
200×200×9.0SHS	14.7
6.0SHS	21.8
5.0SHS	26.0
150×150×9.0SHS	14.9
6.0SHS	22.0
5.0SHS	26.2
125×125×9.0SHS	15.1
6.0SHS	22.1
5.0SHS	26.3
100×100×9.0SHS	15.4
6.0SHS	22.4
5.0SHS	26.6
89×89×6.0SHS	22.5
5.0SHS	26.7
75×75×6.0SHS	22.8
5.0SHS	27.0

hot-rolled sections



section	k_{sm}
610UB125	16.7
113	18.3
101	20.3
530UB 92.4	20.0
82.0	22.4
460UB 82.1	20.0
74.6	21.9
67.1	24.2
410UB 659.7	24.8
53.7	27.4
360UB 56.7	24.1
50.7	26.8
310UB 46.2	26.8
250UB 37.3	28.6

section	k_{sm}
310UC158	11.6
137	13.3
118	15.3
96.8	18.4
250UC 89.5	16.8
72.9	20.3
200UC 59.5	20.2
52.2	22.8
46.2	25.6
150UC 37.2	24.4
30.0	29.7