FIRE CODE REFORM

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FIRE SAFETY IN SHOPPING CENTRES

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FINAL RESEARCH REPORT

PROJECT 6

FIRE CODE REFORM RESEARCH PROGRAM

IMPORTANT NOTES RELATING TO USE OF THIS DOCUMENT

This document identifies the activities undertaken and conclusions drawn from a major research project executed in regard to fire safety issues of sprinklered shopping centre premises in Australia, of up to 4 storeys in height. This document does NOT constitute a design Code and does NOT detail all the engineering technology required for building fire safety design.

The contents of the document have been assembled by eminent Australian fire engineers and scientists and have been derived from various sources which are believed to be appropriate to provide the best information available internationally at the time of publication. This information is provided in an advisory manner and is not claimed to be an exhaustive treatment of all the related subject matters.

Neither the authors, Fire Code Reform Centre Limited, nor any of the organisations and individuals which have participated in the research activities, or have contributed financially to its execution, warrant or make any representation whatsoever that the information contained in this document, or the procedures and methodologies set out in it, or any advise derived therefrom, *will* be suitable for all fire engineered, building fire safety designs.

The information contained herein is intended primarily for the benefit of suitably qualified and competent fire engineering practitioners, who are fully familiar with the capricious nature of fire and the behaviour of materials, structures and people when exposed to fire hazards. Fire engineering design activities require the application of professional knowledge, engineering judgements and appropriate understanding of the assumptions, limitations and uncertainties involved.

Nonetheless, in addition to suitably qualified and competent fire engineering practitioners, it is considered that the information contained in this document will also be of interest to other parties involved in building design, construction and refurbishment and to those regulatory officials, fire service personnel and building surveyors who are involved in assessment and checking of the fire safety designs submitted for approval.

Whilst the procedures and methodologies described in this document may be referred to in support of specific building fire safety proposals, before implementation such proposals must always be approved by the appropriate Authority Having Jurisdiction to confirm compliance (as a minimum) with any applicable building fire safety regulations.

FOREWORD

Underlying the foundation and operation of Fire Code Reform Centre Limited (FCRC) is an endeavour to draw together all the major participants having interest in building fire safety in Australia and through a cooperative effort ensure execution and management of research appropriate to the development of technically advanced fire codes and regulations by the Australian Building Codes Board (ABCB).

Representatives from regulatory authorities, industry and research organisations jointly formulated FCRC's initial Research Program and since 1994 have assisted in contributing funds and directing its activities.

Research Project 6, described in this document, was not originally included in FCRC's Program but was advocated in late 1995 by Mr Max Croxford, Commissioner of Building Control in Victoria. He recognised that shopping centres represent a key area of Australian construction activities offering prime opportunity for investigation of cost-effective fire safety design solutions.

His early proposals contemplated research in Victoria of specific aspects of shopping centre construction but joint negotiation subsequently identified the advantages of wider scope and structuring of the project as a component of FCRC's national Research Program, in order that the activities undertaken could contribute to and benefit from the work being done on other projects being administered concurrently.

Project 6 been financed wholly by contributions secured from within Victoria at the instigation of the Building Control Commission. On behalf of all who will benefit from the output of this research, I record appreciation for this significant contribution to this country's fire code reform endeavours.

Although many parties have been involved during the 21 months duration of Project 6, special recognition must be made of the dedication and professional expertise of the team at BHP Research, Melbourne Laboratories which have provided research leadership throughout this period and thanks are extended to all the participants associated with this work.

The extensive research reported in this document has identified significant opportunities for greater efficiency and flexibility in the design and operation of fire protection facilities in shopping centre developments and refurbishments. The concepts outlined have the potential to save many million dollars for investors, managers and operators of this class of property in the future.

The Project 6 research conclusions have been forwarded to members of ABCB's Building Codes Committee and work is now in hand for appropriate recommendations to be adopted into Australia's building regulatory procedures.

Dr John Nutt AM

Chairman, Fire Code Reform Centre Limited.

EXECUTIVE SUMMARY

The construction of large shopping centres is an area of commercial development which is being pursued very actively in Australia at present. There is a belief that some aspects of the current regulatory fire requirements for these buildings may be unnecessarily onerous, imposing financial burdens on developers and owners and which do not relate to the risk to life from fire in these buildings. The remit of Fire Code Reform Centre Project 6 is to review the requirements in the BCA which apply to low-rise sprinklered shopping centres, and to propose a more rationally-based set of fire-safety requirements which will 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.

This report covers the following areas: current BCA requirements; the results of a survey of aspects of shopping centres relevant to fire safety; key issues; historical incidents in retail buildings; fire statistics; a summary of the fire test results; sprinkler effectiveness; fire scenarios; occupant response and movement; smoke management; the building structure; fire brigade involvement; and property protection.

Some of the main conclusions are:

- Statistical data from the USA and the more limited data from Australia show that shopping centre buildings do *not* present a significant risk to life from fire. The average fatality rate for such buildings in the USA indicates a death rate of 0.74 per 1000 fires reported to the fire brigade. A high proportion of fatalities in these buildings are associated with those who are asleep or intimately involved with ignition and flammable liquids. The above death rate does not take into account the *beneficial effects of sprinklers* and is exactly *one tenth* of that associated with *residential buildings* in the USA. If the occupants in a shopping centre building are awake and aware, it is very unlikely that they will perish in a fire. *From the USA data, sprinklers appear to reduce the death rate by about a factor of three.*

- There is a general trend, as might be expected, for the numbers of civilian deaths and injuries to increase with size of the fire. If by some means, all fires could be confined to the object first ignited, then the civilian fatality rate would probably fall by a factor of nine.

- More fires occur during normal operating hours due to the greater demand on electricity, heating, cooking and the use of appliances. Nevertheless the *majority* of these fires are detected by the occupants and extinguished before they extend beyond the area of fire origin. These are small fires (termed C1 fires) to which the fire brigade may or may not be called. The occupants therefore have a major impact on controlling fires in these buildings.

- Sprinklers also have a very significant impact on whether fires are confined to the area of fire origin.

- The effectiveness of a sprinkler system in these buildings is most dependent on how it is managed. The system must be *soundly managed* in accordance with the principles given in Section 7.3 in order to minimise the times for which the sprinkler zones are isolated. If this is the case, and the sprinklers are designed to be commensurate with the hazard, then the average effectiveness can be taken as 98.5% for sprinkler zones associated with specialty shops and 99.5% for sprinkler zones associated with major stores. This compares with an average effectiveness of 86% associated with retail buildings in the USA. Thus buildings in Australia with well managed sprinkler systems would be expected to offer a higher level of fire safety.

- Sprinklers associated with major stores should be separately valved to those associated with specialty shop areas and each valve should relate to only one level in the building. Any reduction in sprinkler zone size for specialty shop areas is to be encouraged provided that any subsidiary valves are monitored and positioned in appropriate locations.

- The presence of a soundly managed sprinkler system means that the probability of having a fire which goes beyond the area of fire origin and is not controlled by the sprinklers (described as a C3 fire) is *extremely* small. In considering the impact of fire in these buildings it was concluded that the *primary* design fires for these buildings should be *sprinklered* fires (ie. C2 fires). Specific recommendations are given in respect of the appropriate sprinklered fire for various parts of the building. It is also necessary to *consider* the impact of a *credible* C3 fire, to ensure that even in that situation, successful evacuation is possible. However, the margin of safety adopted when considering the C3 fire should be considerably lower than when designing the building for a C2 fire, due to the fact that the latter fire is more likely than the former.

- Studies of occupant behaviour and movement suggest that fire-emergency “passages”, as commonly provided for emergency egress from the mall, are unlikely to be used by the occupants (including staff) in the event of a fire. Thus shopping centres which are designed around this concept—which is encouraged by current regulations—may not provide a sufficient means of egress in the event of a fire. A better and alternative concept is to utilise the normal exit/entrance routes as evacuation paths and to design the building accordingly.

- In the event of a fire in a shop or store, people will move from the fire-effected area into the mall and then away from the fire. It is most reasonable therefore to design the mall as a “safe place”—a *natural haven* for people seeking to move away from the fire. Specific design recommendations are given and include the requirement for the mall to have "infinite tenability" in the case of a C2 fire, and sufficient normal exit paths and smoke control to allow evacuation of any level within the mall given a C3 fire. Normal exit paths include open stairs and escalators within the mall to other levels and direct horizontal access paths to safe places such as adjacent carparks and street level outside.

- As far as smoke management of major stores is concerned it is recommended that the exits comply with the current deemed to satisfy requirements of the BCA with the exception that the entrance to the mall also be considered as an exit. Major stores should be designed to allow evacuation in the event of both C2 and C3 fires.
- For specialty shops, the maximum distance of travel to an exit (ie. into a safe place or to an open space) should not exceed 20 m.
- The presence of an Evacuation Management Plan and associated training is of fundamental importance. The training of wardens should be sufficient to allow them to have a positive impact on any evacuation.
- The building structure must have structural adequacy sufficient to ensure that, when subject to a fire, it does not interfere with the ability of the occupants to move away from the fire. The current requirements for shopping centre buildings having a rise in storey of 4 are based on those for high-rise buildings which are tall with respect to their height, and which have very limited means for egress. Shopping centre buildings, as noted previously, are wide with respect to their height, with many routes for evacuation and much structural redundancy. These buildings should not be designed as high-rise construction.
- The primary design fire for considering the impact of the building structure (when subject to fire) on the occupants, is a sprinklered fire (C2 fire). However, it is also necessary to *consider* the impact of a credible C3 fire, to show that even in that situation, successful evacuation is possible. The findings from the sprinklered tests, conducted as part of this project, indicate that lightweight members will *not* be significantly affected by exposure to a sprinklered fire—even if no ceiling is present. That is, sprinklered fires have negligible effect on the building structure.
- The building structure when subject to a C3 fire should have sufficient fire resistance to allow the movement of the occupants to a safe place. The fire resistance required should therefore relate directly to the time it takes for the occupants to move to a safe place. The areas within a shopping centre capable of having a significant C3 fire are the specialty and major stores. The widespread use of combustible construction materials within large shopping centres has been rare, and as a result, it has not been possible to fully evaluate the impact of such materials on fire safety within these buildings. The mall areas, which provide the primary

means of escape for occupants, must be constructed in such a way as to minimise the risk of spread of flame in the event of a C3 fire. To achieve this, it is recommended that ceilings in malls and walkways are group D materials (eg. masonry; gypsum plaster, paper faced and painted; some fire-retarded timbers and timber products) as defined by FCRC Project 2.

- Within the established limits of the shopping centres studied, the most critical part of these buildings was identified as a department store with a rise in storey of 4. This case was studied to determine the effect of egress path—ie. fire-isolated stairs or direct horizontal access to a safe place outside the department store—on the time for movement to a safe place and therefore the associated requirements for floors and columns at various levels within the building. The following conclusions were reached for members within a sprinklered shopping centre building with a rise in storey of up to four:
    - columns associated with the upper two storeys of these buildings may be constructed with 15 minutes fire resistance
    - columns which provide support to two or three upper levels should be designed to have a fire-resistance level of 30 minutes
    - floors should be constructed with 15 minutes fire resistance
    - internal, non-loadbearing walls between occupancies may be of protected lightweight construction, incorporating combustible or non-combustible framing: linings to these walls must comply with clause C1.10 of the BCA
    - walls separating a carpark from the rest of the shopping centre, and associated with fire-isolated exit shafts within major stores, should be designed to have a fire-resistance level of 30 minutes
    - materials of construction should comply with the general requirements of BCA clause C1.10: any restrictions which currently exist on the use of materials for ceilings and linings remain unchanged except that ceilings in malls (and walkways) should be non-combustible for the reasons noted above.
- The use of fire shutters which close off parts of the building to restrict compartment sizes should be avoided across circulation routes.
- As far as fire fighting is concerned, the intervention of the occupants is important. This, combined with a soundly managed sprinkler system, will most affectively allow the fire brigade to extinguish fires in these buildings. This reinforces the need for

basic fire fighting training for staff and of the provision of appropriate facilities—portable extinguishers and hose reels. Extinguishers are best provided in specialty shops and major stores. For a very large building, it may be appropriate—due to the length of time taken for the fire brigade to arrive at the fire location—to have some staff trained in fire fighting beyond the use of hose reels and extinguishers and to provide in-house booster pumps and specialist hose lines that could be fitted to hydrants. These staff will best understand the building layout and be able to source the origin of the fire more rapidly than the fire brigade. This is not to suggest that they replace the function of the brigade, but that their early intervention would be effective in virtually eliminating C3 fires (which are very rare anyway) during the normal operating hours of the building.

- As far as fire brigade access to the site is concerned, it is important that the fire brigade has access to major entrances of the building, but the provision of continuous vehicular access as required by BCA cl C2.4 is not necessary provided the brigade can be directed to the appropriate entrance.

- High levels of fire safety will only be achieved in these buildings provided all fire-safety systems (particularly sprinkler) are properly commissioned and managed throughout the life of the building. Specific management plans should be developed, implemented, and audited on a regular basis, to maximise the effectiveness of these systems.

CONTENTS

GLOSSARY OF TERMS

Appliance (fire fighting)	—	a fire-fighting vehicle
Concessions	—	small retail outlets located generally within the mall
C1 fires	—	fires which are kept small without the presence of sprinklers.
C2 fires	—	fires controlled by the presence of sprinklers.
C3 fires	—	fires which are typically more severe than C1 and C2 fires.
Department Stores	—	multi-level major stores with levels interconnected by means of transportation such as lifts, escalators/travelators, or stairs.
Day Time	—	defined as being the hours between 8am and 10pm.
Fire Safety	—	safety in fire with respect to both life and property.
GLAR	—	gross lettable area for retail
Life Safety	—	safety in fire with respect to life safety only.
Major Stores	—	shops with a floor area greater than 1000m^2 including both single storey variety and multi-level department stores.
Mall	—	a part of the building that primarily provides access to both major stores and specialty shops at all levels within the building.
Night Time	—	defined as being between 10pm and 8am.
Property Protection	—	protection of the contents of the building and the building itself against the effects of fire.
Safe Place	—	a properly designed location with a shopping centre building which provides a nature haven for people in the event of a fire.
Shopping Centre	—	a combination of specialty shops and majors stores usually interconnected by a mall.
Specialty Shops	—	shops with a particular theme having a floor area less than 1000m^2.
System Effectiveness	—	a combination of system reliability and efficacy, often the product of the two parameters.
System Efficacy	—	represented by a number between 0 and 1 which gives the level of performance of the system when compared with the level presumed by a standard or code.
System Reliability	—	represented by a number between 0 and 1 which gives the probability that the system will operate.

1. INTRODUCTION

1.1 SCOPE

The work undertaken in this research project and reported herein applies directly to low-rise *sprinklered* shopping centre buildings having a rise in storey of up to four.

Modern shopping centres are buildings which contain multiple classes when considered with respect to the Building Code of Australia (BCA) [1,2]. This report considers buildings which 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 however, apply to retail “warehouse” buildings where goods are stored in racks above 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 and other related reports could 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 have been addressed in this project and are considered in this report.

1.2 BACKGROUND

What is the effect of building regulations on *fire safety*[1] and are there other factors that have a significant influence? Putting it more simply: are buildings safe *despite* building regulation requirements or *because* of them, and which requirements have an impact? These questions are of paramount importance in developing effective economic approaches to fire safety in buildings. They are addressed in this project.

The construction of large shopping centres is an area of commercial development which is being pursued very actively in Australia at present. There is a belief that some aspects of the current regulatory fire requirements for these buildings may be unnecessarily onerous, imposing financial burdens on developers and owners which do not relate to the risk to life from fire in these buildings. The remit of Fire Code Reform Centre Project 6 is to review the requirements in the BCA which apply to low-rise sprinklered shopping centres, and to propose a more rationally-based set of fire requirements which will 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.

[1] “Fire safety” in this context includes both “life safety” and “property protection”.

1.3 FIRE ENGINEERING FRAMEWORK

The *Fire Engineering Guidelines* [3] provide an excellent overview for the application of fire engineering to particular design situations including the design process, developing a *fire engineering design brief*, identifying the appropriate level of quantified analysis, and undertaking an appropriate fire scenario analysis. Such an approach has been adopted in this study and it is believed that the data presented in this and related project reports provide information which will be useful in undertaking specific fire engineering studies of retail buildings.

One aspect of particular importance considered in [3] is the *design process* (see Figure 1.1) which recognises the role and sequence of feasibility study and conceptual design prior to design documentation, construction, commissioning, and management-in-use phases in achieving adequate fire safety. Although *management-in-use* should *extend* to include such matters as occupant fire fighting, training, building awareness (or surveillance) and evacuation management.

It is sometimes assumed that the primary level of fire safety in buildings comes from what is constructed and put in place, as opposed to the commissioning and ongoing management of installed systems. This is often not the case and the *Guidelines* remind designers of this fact. A *fire engineering design* must address these other issues.

1.4 METHOD OF APPROACH

It is not possible to have 100% safety in any building or with any activity. This is due to our incomplete knowledge about any subject and therefore our inability to predict all aspects of behaviour and sequences of events in the future. This is not to suggest that *high* levels of safety cannot be achieved but rather that the word *safe* must be not be considered in any *absolute* sense. Thus one building can be designed to be *safer* or *as safe* as another, assuming that one understands the factors that have an influence on fire safety.

Building regulations have traditionally been developed in response to various “disasters” and the solutions incorporated in the regulations have sometimes resulted from the pressure to “put something into place” without any real knowledge or understanding as to whether that measure will work or not. It may well be that there are much more effective ways of *improving* the level of safety than the action taken. Therefore, as already suggested in the introduction to this report, one cannot assume that all of the current regulatory requirements for retail buildings have a significant impact on fire safety.

It follows from the above discussion that our response to disasters and the development of management protocols and fire-safety regulations should be based on a sound risk-engineering approach and is a function of the following:

- *Understanding the Past* —A really good understanding of the likely impact of various factors can be obtained by studying the past. This is best done from a *substantial* statistical base and may be supplemented by “anecdotal” evidence—although care must be exercised with the use of this data.

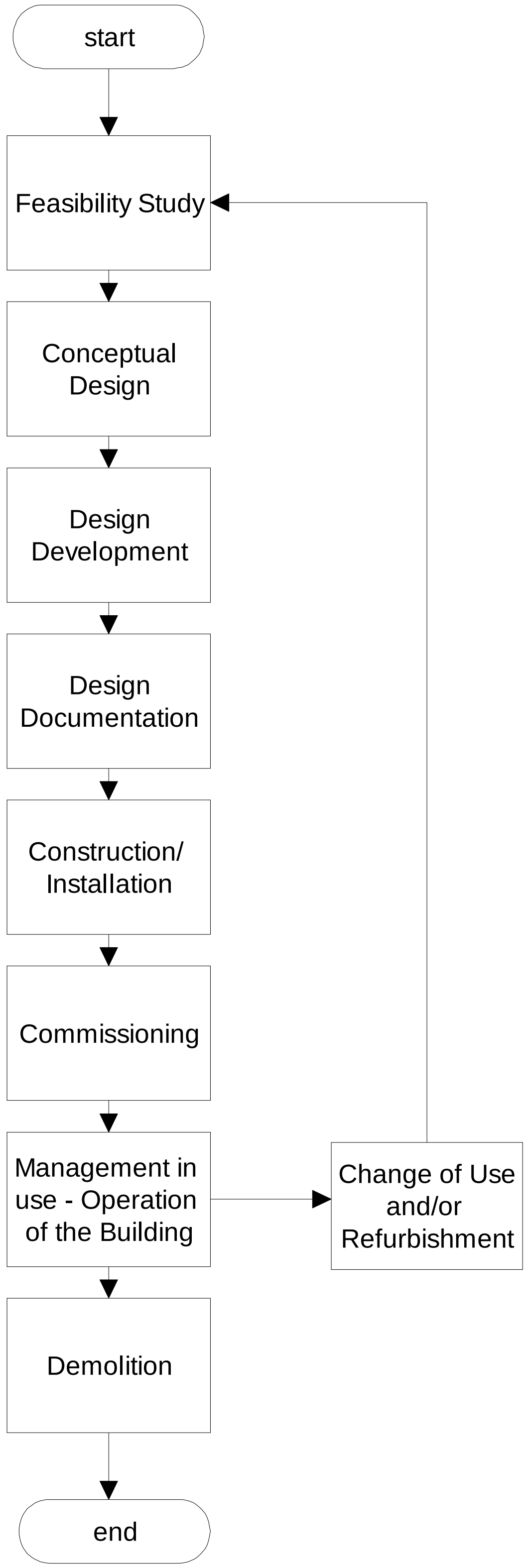


FIGURE 1.1 GENERALISED PROJECT DELIVERY PROCESS

- *Understanding the Situations being Studied*—A thorough knowledge and understanding of the situations being studied is essential. In the case of shopping centre buildings, this includes the buildings, the characteristics of fires that may occur in these buildings, and the action and reliability of the various fire-safety systems.

The method of approach adopted in this project has been consistent with the above observations and has been structured to generally comply with the design process given in [3] (see Section 1.3). It is broken into the parts listed below. Other related project reports dealing specifically with some of these parts have been published and are referenced below; where parts are not referenced they are dealt with in the present report.

- Understand current BCA requirements [4].
- Undertake an in-depth survey and study of current shopping centres [5].
- Identify the key issues and objectives of the project [6].
- Collect and analyse published accounts of fires in retail buildings [7].
- Obtain and review fire statistics for USA and Australian buildings [8-10].
- Undertake fire tests to better understand fire characteristics [11].
- Determine the effectiveness (ie. efficacy and reliability) of sprinkler and smoke exhaust/venting systems [12] based on historical data and fault tree analysis.
- Determine the various fire scenarios that can occur in shopping centres and their probability of occurrence given a fire start and the various fire safety systems.
- Understand the behaviour of occupants in the building both with respect to fire fighting and evacuation.
- Understand the role and impact of the fire brigade in relation to each fire scenario.
- Study the impact of smoke, associated with the range of fire scenarios, on the occupants of the building taking into account smoke exhaust and venting, building geometry, occupant behaviour and types and positions of exits.
- Study the role of the building structure in providing fire safety and determine the fire-resistance levels required for the various parts of the building, taking into account the range of fire scenarios.
- Evaluate other BCA requirements relating to aspects of building construction—doors, mixed occupancy parts of buildings, building considered as atriums.
- Determine conclusions and recommendations based on the above parts of the research project.

1.5 Report Overview

This report gives an overview of the work and outcomes associated with each of the project parts described in the previous section. It seeks to give the reader a clear understanding of the issues and findings and gives specific recommendations for regulatory change. It is structured as follows:

§1. *Introduction.*

§2. *BCA Requirements and Key Issues*—summarises current requirements and identifies specific regulations and areas for consideration due to cost or safety concerns. That is, this section identifies the issues that are to be addressed within this report.

§3. *Fire Incidents in Retail Premises*—summarises the history and apparent lessons associated with fires in retail buildings.

§4. *Fire Statistics*—gives a summary of the finding of a detailed statistical study of retail fires in the USA.

§5. *Survey of Shopping Centres*—gives a summary of a comprehensive study of a major shopping centre and visits to eleven shopping centres.

§6. *Fire Tests*—provides a summary of the fire tests that have been conducted as part of this project and the significant findings.

§7. *Sprinkler Effectiveness*—considers the reliability and efficacy of sprinklers, how to make sprinklers more reliable, and whether sprinklers should always be required for high roof areas.

§8. *Fire Scenarios*—describes the range of various fire scenarios, their likelihood, and their potential impact on the occupants and building.

§9. *Building Layouts*—describes a building layout that has been selected to provide a realistic example of a shopping centre for the purposes of discussion and illustration.

§10. *Occupant Response and Movement*— considers the response of the occupants to fire cues and the time for movement to a safe place.

§11. *Smoke Management*—considers the presence of smoke in the building, its impact on both life safety and property protection, and the effectiveness of various smoke management strategies.

§12. *Building Structure-Fire Resistant Levels*—considers the role of the building structure in providing fire safety and determine the fire-resistance levels required for the various parts of the building, taking into account the range of fire scenarios.

§13. *Building Structure-Other Issues*—considers other BCA requirements relating to aspects of building construction—doors, mixed occupancy parts of buildings, building considered as atriums.

§14. *Fire Brigade Involvement*—considers the impact of the fire brigade on the various fire scenarios, and conversely, the effect of these fire scenarios on the brigade.

§15. *Protection of Property*— considers the issues related to property protection.

§16. *Conclusions and Recommendations*—summarises the findings from the previous chapters and presents corresponding conclusions and recommendations.

Detailed calculations and background data are presented in Appendices, and in [4] to [12].

2. BCA REQUIREMENTS AND KEY ISSUES

A previous report [4] has analysed in detail the requirements for shopping centres as called up in the 1990 edition of the BCA. The 1996 version of the BCA (hereafter referred to as BCA '96) recasts the code into performance terms with the performance level that must be achieved implied by the deemed-to-satisfy provisions. Some of the provisions have changed from those in the BCA '90 but little has changed that directly affects this project; nevertheless, any changes are considered where appropriate. One difficulty with an attempt to review the provisions has always been that the BCA requirements have arisen over a long period of time and from amalgamations of earlier documents, and the reasons behind individual requirements are sometimes far from clear. This is still largely the case with BCA '96.

In attempting to determine how normal provisions may be modified in the light of alternative solutions, the BCA frequently makes use of the term 'concessions'. As these alternative requirements are permitted within the code, it follows that they must be considered to correspond to an *equivalent* level of safety in certain situations—namely the situations specified in the 'concession'. The use of the word 'concession' unfortunately implies a lower level of safety, which is not the case. The use of the term has therefore been avoided in the Project 6 documentation.

Many of the provisions in the BCA appear to apply to shopping centres by default, having arisen from more general building requirements. However, shopping centres have very particular attributes which contribute to fire safety by means of design, construction and use. For example, the layout of a typical shopping centre is fairly simple, and the wide malls invariably lead to large exits to outside—this being necessary to provide the "sense of openness" and to allow the efficient movement of people. The occupants are alert and generally mobile, and the shopping centres are subject to a high level of management control. Security surveillance is common, and this combined with maintenance activities, have the effect of identifying and reducing fire starts. By allowing the regulations for shopping centres to be comparable with more general requirements, it has not been possible in the past to take advantage of this combination of inherent fire safety features. In fact the analysis of BCA provisions suggests that rather the reverse is perceived to be the case: shopping malls and atriums attract very severe requirements (eg. in relation to smoke management and fire-resistance levels) for which very few if any benefits are conceded.

At the end of each of the following parts, a simple summary is given of the key issues [6] to be addressed in this report.

2.1 FIRE RESISTANCE AND COMPARTMENTATION

The fire resistance level (FRL) required for structural elements within a shopping centre varies depends on the *type of construction* required which, in turn, is largely a function of the floor area of the compartment or building and its *rise in storey*. The specific FRL requirements are summarised in detail in [4].

Table C2.2 in the BCA relates the type of construction required to the floor area and volume of the compartment (or building if there is only one compartment). Modern shopping centres, due to the substantial openings at each floor level must be considered as one compartment. These compartmentation requirements are therefore not usually relevant, because shopping centres generally have to satisfy the requirements for *large isolated buildings* (BCA cl C2.3) which means that they have full sprinkler systems, access for fire fighting vehicles (BCA cl C2.4 (b)) and smoke exhaust or smoke and heat vents. There is no BCA requirement to sub-compartment sole occupancy units, a classification which would apply to most shops.

The Type of construction required is also sensitive to the rise in storey. For example, a building with a rise in storey of two which incorporates two basement levels is Type C construction (least fire resisting) whilst a building with a rise in storey of four with no basements is Type A construction[2]. Type B construction is required if the building has a rise in storey of three. In Type B construction, according to Table 4 in Specification C1.1, fire walls, common walls, internal columns and external walls are required to have a fire-resistance level—but there is no such requirement for the floors or roof. Of course, because of 'support of another part' requirements, the BCA (Spec C1.1, cl C2.2) requires the floors to have an FRL unless it can be shown that the columns can achieve the required fire resistance without the presence of lateral support from the floors. On a related matter, it should be noted that internal columns and loadbearing internal walls (other than firewalls) within the top storey of a building of Type A construction (BCA Spec C1.1, cl 3.7) require no FRL provided the rise in storey is not greater than three (and 60 minutes if the rise in storey is greater than 3).

Because the fire resistance requirements vary with *rise in storey*, it is beneficial from a code standpoint in some cases to separate a shopping centre with areas of different heights (and therefore different types of construction) by fire walls. Access through a fire wall must be by means of fire doors or protected shutters. Fire doors in daily use are found to be subject to substantial damage and expensive to replace, and the use of shutters to be fraught with problems [5].

Shopping centres frequently incorporate buildings or parts having different classifications (carpark, retail building, cinema). According to BCA cl C2.8(a), if such buildings of different classifications are adjacent to each other, then either the elements in both buildings must have an FRL which is the highest associated with each classification, or a fire wall must separate the two buildings. Access between the different classes of buildings is required in practice and openings must therefore be provided through the walls, with the associated disadvantages of fire doors and shutters noted above.

The following key issues are identified:

- What separation should be provided between different classes of building within the one building structure?
- If separation is required, what is an appropriate door construction?
- What fire-resistance levels are required for columns, beams, floors and walls?

[2] The basement levels must have additional exit paths to ground level.

2.2 EVACUATION

The BCA (cl D1.4) gives requirements with respect to the maximum distance to an exit which frequently requires the construction of fire-isolated passages for people to evacuate from the mall, and the introduction of fire-isolated stairs from the upper levels which would not be required for normal circulation. These routes may not be used for service access to the shops without the introduction of smoke lobbies or pressurisation, and occupy space that could be used for sales purposes. The BCA (cl D1.6) specifies the total width of exits required.

Emergency Warning and Intercommunication Systems (EWIS) are only required by the BCA if the building is greater than 25 m, or contains an atrium or a cinema. In view of the large numbers of people which could be in a shopping centre at busy times, the question could be raised as to whether an emergency warning system should be required for all shopping centres having a floor area greater than a limiting size. Indeed such systems are common in larger centres.

In summary, the following matters are raised:

- What exit spacing and width requirements should apply for these buildings?
- What areas within a shopping centre should be isolated with walls to facilitate safe egress and what is an appropriate door construction at openings?
- Should an EWIS be required?
- If an EWIS is required, what should be its characteristics—WIP's, type of evacuation signals, initiation of evacuation signal ?

2.3 EMERGENCY VEHICLE ACCESS

One of the requirements for large isolated buildings in the BCA (namely C2.4(b)) is that vehicular access must be provided around the whole perimeter of the building for fire fighting and other emergency vehicles This requirement may interfere with efficient car park design.

- What access is required for fire-fighting and other emergency vehicles?
- Are the vehicular access requirements of C2.4(b) necessary?

2.4 FIRE FIGHTING PROVISIONS

2.4.1 HYDRANTS

Fire hydrants are required to be installed in buildings having a total floor area greater than 500 m^2 and when an operational fire service is available to attend the building fire. The BCA (E1.3 (b)) and AS 2419 [13] specifies the location of internal hydrants, types and location of on-site pump sets and water supply criteria.

2.4.2 FIRE CONTROL CENTRES

The BCA (cl E1.8) requires a “fire control centre” in accordance with Spec E1.8 if the building is more than 25 m high or if it has a total floor area exceeding 18000 m^2. The latter will usually be the case for shopping centre buildings.

Spec E1.8 specifies the requirements for fire control centres. It states that these centres are to:

- provide an area from which fire fighting operations and other emergencies can be directed; and
- contain controls, panels etc. associated with the required fire services in the building; and
- not be used for any other activities.

Extensive details of the requirements for these rooms are given in Spec E1.8.

The following issues arise:

- ♦ Are hydrants required within the building?
- ♦ If this is the case, where should these hydrants be best located?
- ♦ Under what circumstances are fire control centres necessary?

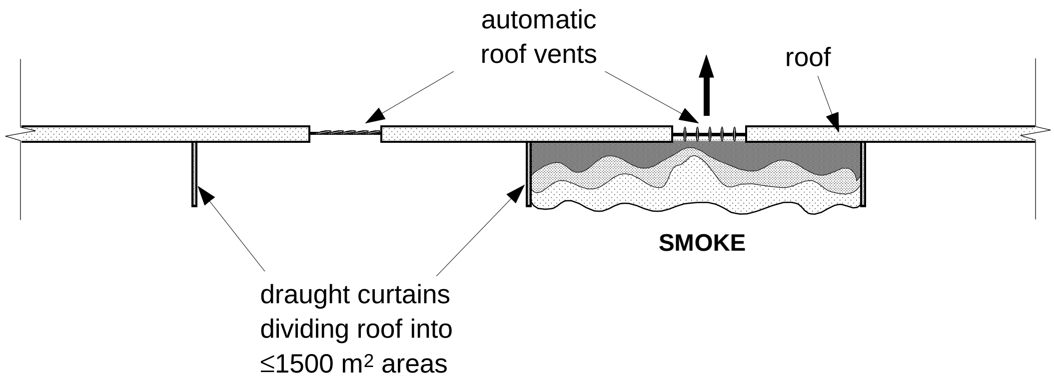
2.5 SMOKE CONTROL

The deemed-to-satisfy provisions of the BCA result in quite onerous requirements for smoke control systems in malls and atria, which are highly expensive, and in some cases require complex control systems for the possibility of successful operation. BCA ’96 will give designers the opportunity to design possibly less onerous systems taking into account other parts of the fire safety system and the behaviour and movement of the occupants. Such an approach will require a rational evaluation of possible fire scenarios (and therefore design fires) and the associated need for smoke control.

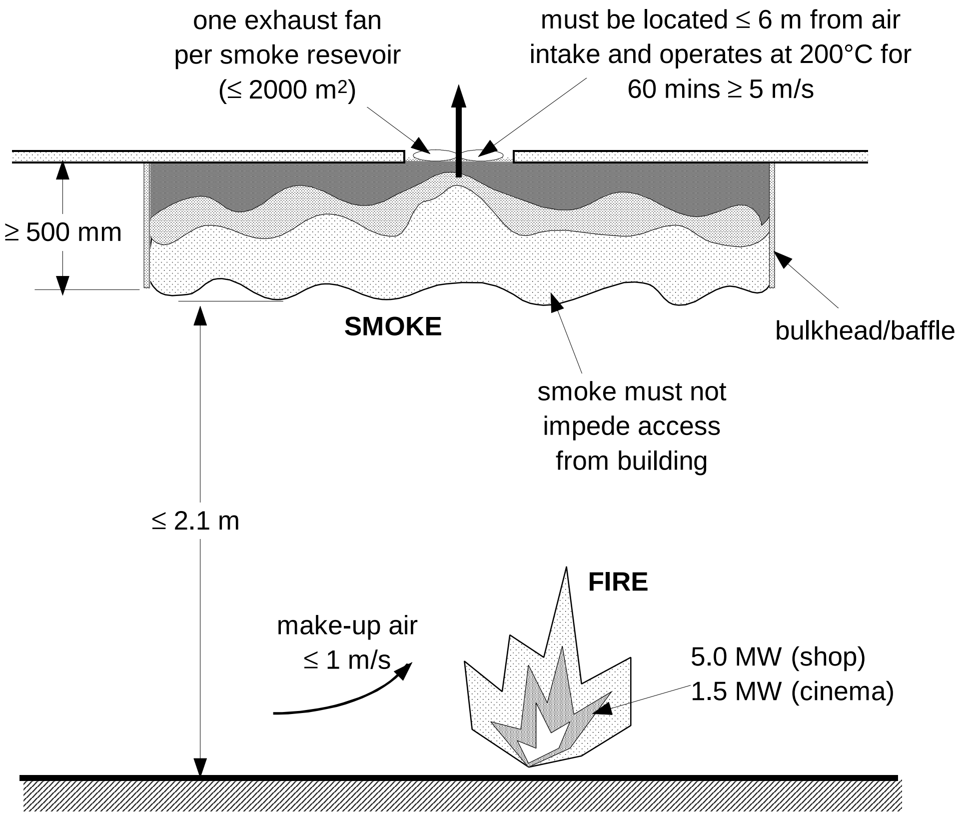
There are many factors associated with the management of the smoke hazard in these buildings. Smoke exhaust or venting systems may form part of a smoke hazard management system. Depending on the floor area of the shopping centre and whether there is a covered walkway or mall, the BCA may require smoke exhaust for the mall and this will be achieved by reservoirs and fans or vents (Figure 2.1 -*see Figures 7.4 (a) and 7.5 (a) in* [4]). Shops greater than 1000m^2 and opening into the mall are required to have a dedicated smoke exhaust system, which again, will require exhaust fans and bulkheads or baffles. If a major store is a multi-storey single compartment then the system must satisfy the requirements shown schematically in Figure 2.2 (see Figure 7.6 in [4]). Such systems are complicated and it is important to understand the probability of correct operation.

The following key issues are identified:

- What are the reliabilities of smoke control systems—how often do they work?
- What are appropriate design parameters for smoke control systems?
- What characteristics are required of smoke exhaust/venting systems for fire safety?

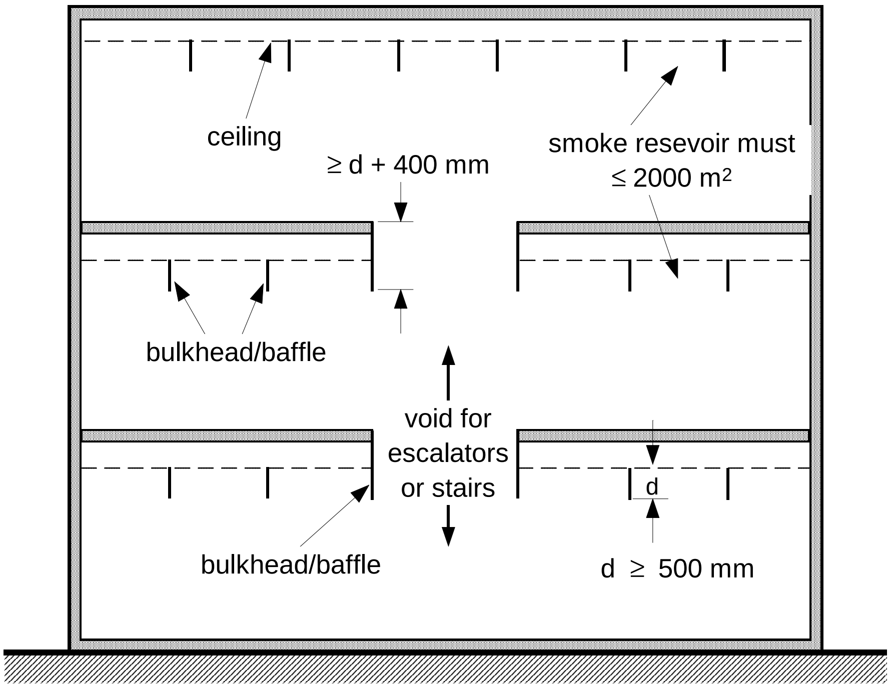


a) roof vents and draught curtains

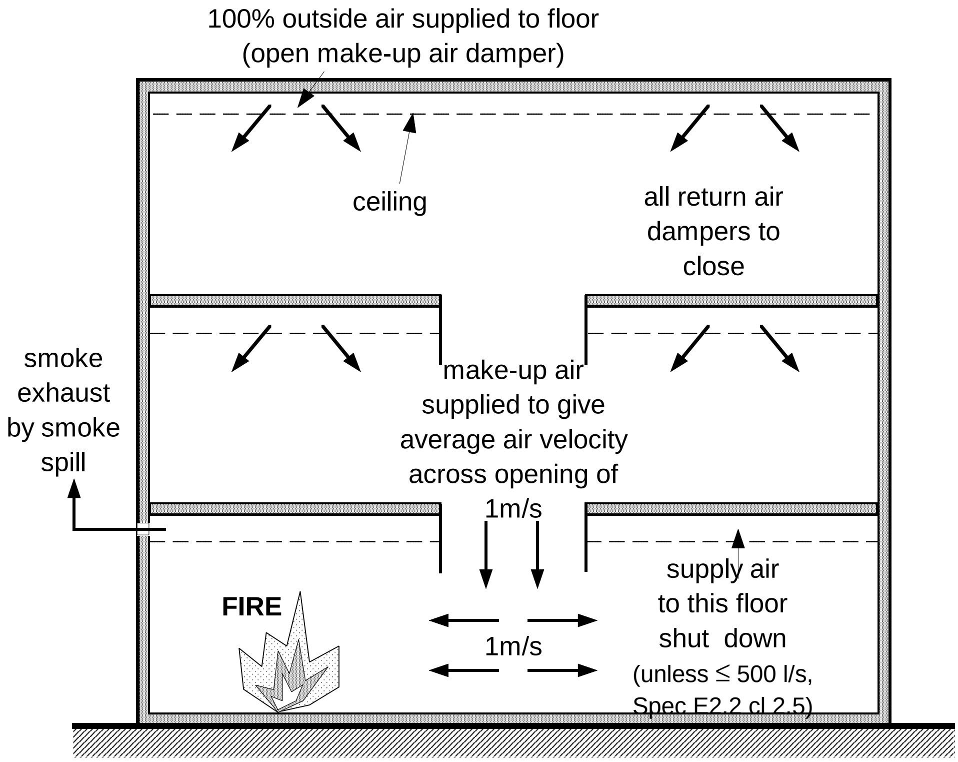


b) Smoke Exhaust Systems

FIGURE 2.1 SMOKE EXHAUST SYSTEMS REQUIRED FOR MALL



a) Smoke Resevoir Requirements



b) Exhaust and Supply in Fire Mode

FIGURE 2.2 SMOKE EXHAUST SYSTEMS REQUIRED FOR MAJOR STORE

2.6 ATRIUM REQUIREMENTS

2.6.1 BACKGROUND

Many shopping centres have “glass roofed” atriums to improve the level of natural light in large deep spaces, to provide visual interest and clearly identifiable access routes between levels. The BCA requirements for atriums are particularly onerous. *In practice, the provisions of the BCA only apply to multi-storey sprinklered shopping centres where an atrium connects more than 3 storeys.*

2.6.2 BOUNDARY WALL CONSTRUCTION

An atrium well typically requires separation from the remainder of the building by bounding wall construction, with a setback of not greater than 3.5 m from the perimeter of the atrium well (see Sections 8.1 and 8.2 of [4]). Boundary wall construction is required by the BCA (cl G3.3) at all levels, with the exception of 3 consecutive storeys if:

(i) one of these storeys is at a level at which direct egress to a road or open space is provided; and

(ii) the sum of the floor areas of those storeys that are contained within the atrium is not more than the maximum area that is permitted in BCA Table C2.2. See Figure 2.3.

Condition (i) is normally achieved within shopping centre atria; however, item (ii) requires extensive compartmentation of the floor levels or the construction of bounding walls within 3.5 m of the atrium well. This is the case since the reference to BCA Table C2.2 means that the specific compartment floor areas given in that table must not be exceeded, whereas if the reference had been to BCA cl C2.2 then the floor areas could have been relaxed in accordance with the large isolated building provisions (ie. cl C2.3).

Bounding wall construction, according to the BCA, must have an FRL of 60/60/60 combined with self-closing fire doors, or consist of toughened safety glass or wired glass with wall wetting sprinklers and self-closing smoke doors. In the former case the construction must extend from floor to floor; in the latter case a fire barrier with an FRL of -/60/30 must be installed in the ceiling space above the line of the glazing.

2.6.3 ROOF SEPARATION

As discussed in Section 8.3 of [4], according to BCA cl G3.6, the roof structure and membrane must have an FRL of 180/60/30, depending on the type of construction, or be protected by a sprinkler system. BCA cl 2.2 of Spec G3.8 gives the conditions under which sprinklers are required in order to wet both the “covering membrane and supporting structure”. Separately, cl 5.4.3 of AS2118 [14] (which is called up by the BCA) requires roofs to be sprinklered. The purpose and effectiveness of roof sprinklering need to be considered.

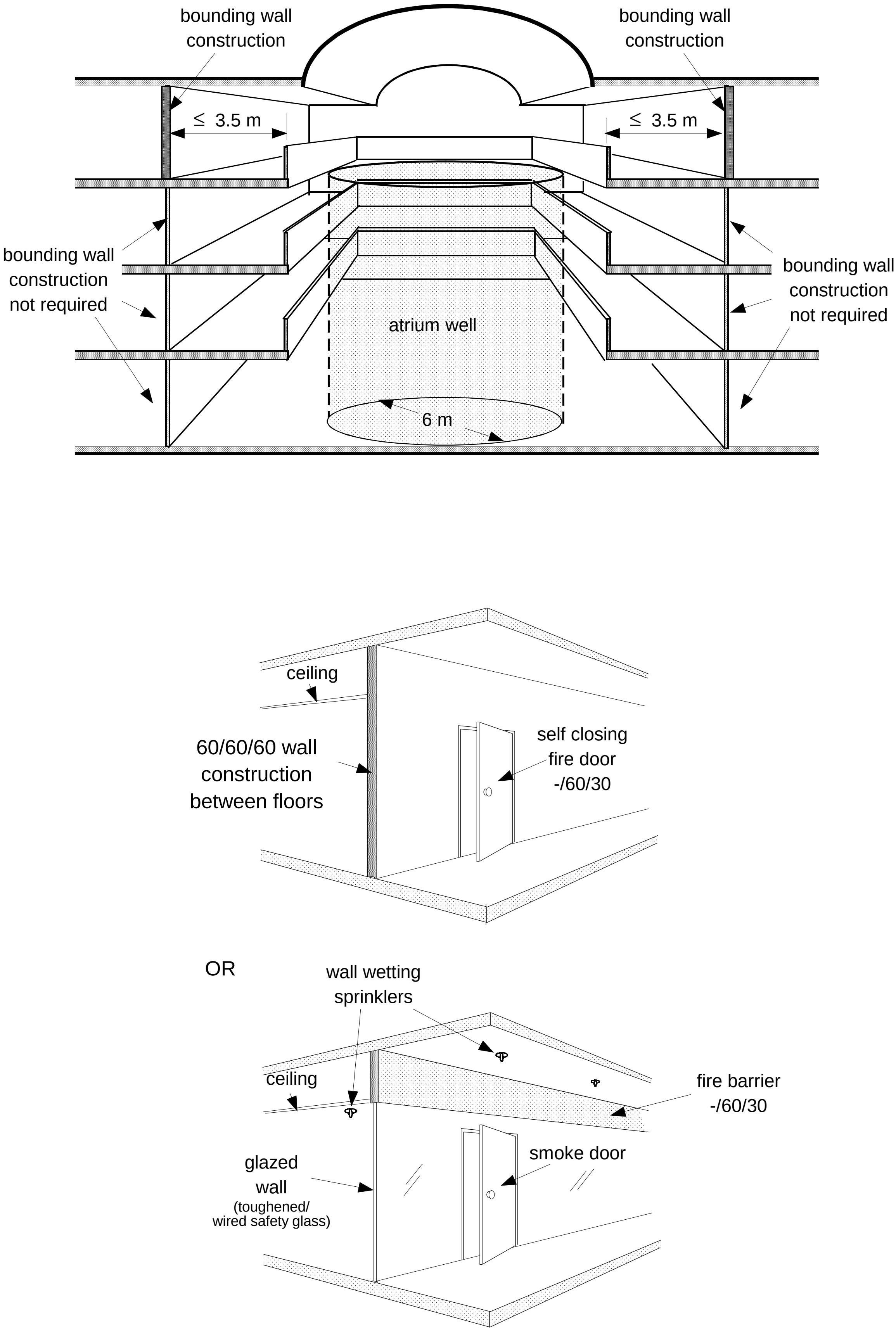


FIGURE 2.3 SEPARATION REQUIREMENTS FOR ATRIUM

2.6.4 FLOOR PROTECTION

According to the BCA (Spec G3.8, cl 2.3), the floor of an atrium must be protected with overhead and/or sidewall fast response sprinklers. This requirements raises the general question of what protection, if any, is required for the floors of atriums and malls?

2.6.5 SMOKE HAZARD MANAGEMENT

The BCA (Spec G3.8, cl 3.7) does not allow the use of smoke or heat vents in an atrium where a Class 6 part of the building adjoins the atrium. However BCA Table E2.2 allows the use of either smoke exhaust or smoke and heat vents in malls or walkways when required. It is difficult to understand why smoke venting is not permitted in this situation, and more generally, why the same types of smoke extraction should not be applicable for both atriums and malls.

Stair pressurisation is required in fire isolated exits in a building containing an atrium, though it would not be required in other low-rise buildings.

BCA Spec G3.8, cl 5 requires all buildings containing an atrium to have an EWIS.

2.6.6 OTHER ASPECTS

Alarm systems required for a building with an atrium include a break-glass fire alarm (ie. manual call point - MCP) at each door to a fire-isolated stairway, ramp, and passage. If a required path of travel to an exit is within an atrium, a suitable alternative power supply must be provided to operate required safety systems, including sprinkler systems and hydrant pumps, air handling systems, alarms, warning and communication systems, and emergency lighting circuits. If this standby supply is within the building, it must be within an enclosure having an FRL of 120/120/120 (see Section 8.5 of [4]).

The following key issues are identified in relation to buildings where the atrium provisions apply:

- ♦ Does boundary wall construction according to BCA cl G3.3 contribute to fire safety?
- ♦ What is the purpose and effectiveness of sprinklering an atrium roof? Is it justified?
- ♦ As far as EWIS are concerned—see issues under Section 2.2.
- ♦ As far as smoke control is concerned—see issues raised in Section 2.5.
- ♦ Under what circumstances are MCP alarms required?
- ♦ Under what circumstances is a standby power supply required?

2.7 SPRINKLERS

It is strongly implied (although not explicitly stated) by BCA Spec E2.2, that the smoke control system for a sprinklered building can be designed for a sprinklered fire *only*. Thus operation of the sprinklers is critical to successful smoke control. Sprinkler reliability is clearly a serious issue for shopping centre fire safety, but the management of sprinkler systems (as opposed to their maintenance) is not covered by the BCA. A Grade III water supply only is required if the building has an effective height of less than 25m and many modern shopping centres, although very big in floor area, are less than 25m in height. Clause 5.4.3 of AS 2118 requires sprinklers to be located at not greater than 450mm below a non-combustible roof (or 300mm below a combustible roof) where there is no ceiling. This rule is currently applied to the mall roofs.

The following issues are identified:

- How reliable are sprinklers in these buildings and how can this be maintained/improved?
- What Grade of water supply is required in buildings having a height of less than 25 m?
- Under what circumstances is it necessary to sprinkler the roof of a mall?

2.8 SUMMARY

The review of the BCA provisions given in [4] provides a useful and succinct summary in one document of all the requirements which apply to shopping centres which are otherwise scattered throughout the BCA. The review has highlighted inconsistencies within some of the requirements themselves, and has given rise to questions as to the value of some others, particularly in relation to atriums. Other issues have arisen from the detailed survey of shopping centre buildings [5]. An attempt has been made in this project to address the issues raised in the foregoing paragraphs and to determine cost-effective solutions which do not compromise fire safety. Discussion of these matters is the purpose of the remaining chapters of this report.

3. FIRE INCIDENTS IN RETAIL PREMISES

3.1 INTRODUCTION

As explained in the introduction to this report, much can be learnt from studying past fire incidents in retail and shopping centre buildings as reported in the literature. Not only can guidance be obtained on the *range* of possible fire scenarios, but a "feel" obtained for the factors that seem to have a significant influence on fire safety. A detailed report describing the results of such case studies has been published [7]. In that study, ninety-seven accounts of fires in retail buildings were considered. These findings are summarised in Section 3.2.

In addition, [7] 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. A summary of the findings is given in Section 3.3.

3.2 SUMMARY OF FINDINGS—CASE STUDIES

The analysis of the case studies revealed a number of apparent trends, although caution should be exercised in drawing general conclusions due to the limited data. In addition, the selection of cases was based on those covered in press reports which are therefore high loss fires or are interesting for other reasons. The following tentative observations can be made:

i. The majority of fires appear to have been started by electrical faults or arson—although the "unknown" category is high. In the case of electrical faults, these were often associated with PVC covered wiring and electrical devices within the ceiling space, display case areas or shop facades and faults from appliances. Several fires were caused by welding work during renovation.

ii. 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. It appears that very few fires were allowed to develop in areas which were directly observable by the occupants.

iii. In a few situations, combustible ceiling tiles led to rapid fire spread across the enclosure leading to a serious fire-safety scenario.

iv. A major mechanism of fire spread to other parts of the building appears to have been through the ceiling space—irrespective of whether there were combustibles in ceiling space. There were many situations where the ceiling space was not sprinklered.

v. In some shopping centres, the decision to install sprinklers in a particular shop appears to be a decision made by the owner of the shop or store. Thus, there are some centres where certain shops are sprinklered but others are not. This is a dangerous practice which can lead to the centre being affectively destroyed—although it was noted, that in some circumstances the fire was prevented from spreading into the sprinklered parts by the action of the sprinklers. Significant water damage was nevertheless experienced due to activation of the heads.

vi. Other cases were noted where the building was essentially sprinklered throughout but where combustibles or combustible construction within parts of the building (eg. ceiling space construction or combustibles associated with verandahs and awnings) allowed a significant fire to develop such that the sprinklers were overwhelmed and not able to adequately control the fire. Unfortunately no information was given on the design delivery rate of sprinkler systems where this occurred.

vii In two cases the sprinkler system had been isolated overnight and fire (which occurred at night) resulted in almost complete destruction of the buildings. One of these buildings incorporated a smoke detection system but this had also been isolated.

viii. It appears that fires that were able to be extinguished rapidly by the fire brigade tended to be small. For this to be the case the brigade had to have arrived and located the fire in a short period of time or the fire had to been kept small due to the action of the occupants or the sprinkler system. In other cases where there were walls giving fire separation (these may not have been required fire-resistant walls) or partial sprinklering, the brigade was able to confine the fire an area such as the shop of fire origin. Otherwise, for the cases reviewed, the extent of flame spread was very large and significant parts of the centre were destroyed. Generally, the fires reported in the literature were larger fires, as these are more “newsworthy” than smaller fires that have been easily extinguished.

3.3 STUDY OF SITUATIONS WHERE DEATHS OCCURRED

The incidence of fire deaths in retail premises in Australia is very small[3], and it is assumed here that the broad conclusions drawn from an analysis of the much larger USA database would be valid for Australian shopping centres. This assumption is borne out by a recent analysis of the statistics for fires in retail premises for New South Wales [9]. The following remarks relate to all fatal fires in retail premises recorded in the NFIRS database.

There have been 86 deaths in 77,996 retail fires over 10 years in the USA giving a death rate of about 1.1 per 1000 fires. This may be contrasted with a rate of deaths in residential buildings in Australia of 7.08 per thousand fires. The nature of these deaths in retail fires has been assessed and it appears that about ten of the victims were asleep at the time of alarm, about twenty were likely to have been asleep and about six more could have been asleep at that time. Of the remainder about seven appear likely to have been involved in incendiary[4] fires, another seven in suspicious fires—in some cases possibly involved in starting the fires or possibly subject to the attack themselves. It appears that fires in or from cars might have resulted in a further two of the fatalities and that a further twelve of the victims were bedridden, too young to act or too old to act, this contributing to their death. It appears that a further sixteen of the victims might have been intimately involved in the ignition (but not in an incendiary or suspicious manner).

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3 For fires in retail premises in New South Wales over the period 1986—1992, there were 2 fatalities.

4 This refers to fires that are started deliberately to cause damage to the building or injury to the occupants.

Thus in these retail buildings it appears that well over one third of the fatalities might have been asleep at the time of ignition, a further one sixth "impaired" in some way (bedridden, too young, too old) resulting in over half of the victims likely to have been unable to respond to the fire. A further one third might have died as a result of having been intimately involved in the ignition (not necessarily in an incendiary or suspicious manner). Thus it appears that over two thirds of the fatalities might have resulted from circumstances and involvement such that the behaviour, age or condition of the person was a significant contributing factor in their death in the fire.

Flammable liquids and to a lesser extent gases seem to have been involved in many of the fires that resulted in civilian fatalities. They were identified as having been involved in fires resulting in 37 of the fatalities, including several with multiple fatalities, and were possibly involved in fires causing a further seventeen fatalities. Included in the latter category are fires in buildings identified as motor vehicle or boat sales or service and where no other cause of fire was identified (that is, if wood, plastic, etc was identified as involved in the ignition, the fires have been excluded from the seventeen mentioned) or other occupancies where incendiary or suspicious was flagged but no other material involvement specified. Thus flammable liquids and gas may have been involved in up to 62% of the fatalities.

There was one fire involving 5 fatalities in a sprinklered building. In this case the sprinklers *operated* and limited the spread of fire to the *area of fire origin*. Again, it appears that flammable liquids were involved with this fire.

4. FIRE STATISTICS

4.1 SOURCES OF DATA

As noted in the previous chapter, a study [8] has been carried out to analyse the statistical data on USA retail fires attended by the fire brigade contained in the NFIRS [15] database for the 10 years 1983 to 1993 excluding 1986 for which data was unavailable. All fires were classified as structure fires, that is building as opposed to vehicle, ship or outdoor fires. The conclusions of the report are very pertinent to the present study. For comparison, a further study was carried out on data available from the NSW Fire Brigades for New South Wales for the years 1986 to 1992 [9]. An analysis of Australian fire statistics for commercial buildings has also been undertaken [10]. 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.

These data are used in various ways throughout this report but a summary of some of the key findings are presented below.

4.2 FATALITY RATE

Firstly it is clear both from the USA data and from the rather more limited data from Australia that retail premises do not present a significant risk to life from fire. The USA data shows that the average fatality rate for civilians (as opposed to fire fighters) is 1.12 deaths per 1000 fires, which may be compared with the figure for residential apartments, from the same source, of 7.4 civilian fatalities per 1000 fires. In New South Wales the comparable figure for retail premises is 0.79 deaths per 1000 fires, but since this is based on only two fatal fire incidents, the figure must be used with caution. There is a general trend, as might be expected, 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 [8] 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.

As explained in Section 3.3, a high proportion of fatalities are associated with those who are asleep or intimately involved with ignition and flammable liquids. Since these factors are perhaps less likely to be present in the shopping centres under consideration it seems likely that the relevant fatality rate is much *lower* than the average USA retail figure of 1.12 civilian deaths per 1000 fires. In fact, the average figure [8] for shopping complexes in the USA is 0.74 deaths per 1000 fires.

4.3 FIRE SPREAD

The USA statistics record the extent of flame damage in the following categories:

- confined to object of origin
- confined to part of room or area of fire origin
- confined to room of fire origin

- confined to fire-rated compartment of fire origin
- confined to floor of fire origin
- confined to structure of origin
- extended beyond structure of fire origin

Where flame damage was recorded, the largest category of fires, 47%, are those confined to the object of fire origin: 80% of fires were confined to the room of fire origin. From the NSW data, the comparable figure for the latter is 78%. Very few fires which spread beyond the room of fire origin are *confined* to the compartment of fire origin. Only 3% of fires where flame damage is recorded spread beyond the structure of fire origin.

4.4 TIME OF DAY

The variation of the extent of flame damage with alarm time is shown in Figure 4.1. More fires occur in the day than at night. However the statistics show that day time fires have a much greater chance of being confined to the object of origin and room of fire origin, whilst night time fires have a greater chance of becoming large. In parallel, the rate of civilian deaths in fire is greater at night, but the rate of injuries is greater in the day (presumably because there are more fires in the day). It must be understood that recorded injuries can be anything from minor smoke irritation to severe burns. Unfortunately insufficient data is available to grade the severity of injuries.

4.5 SPRINKLER PERFORMANCE

Sprinkler performance in the USA statistics is recorded in one of the following categories:

- equipment operated
- equipment should have operated but did not
- equipment present but fire too small to require operation
- no equipment present in room or space of fire origin

The number of fires recorded where there were no sprinklers (or unknown) is substantially greater than when sprinklers were present. Where there were sprinklers in 69% of cases they did not operate, but the overwhelming majority (93.5%) of these were recorded as being because the fire was too small. The proportion of fires where the sprinklers were present and should have operated (but did not) is therefore quite small, suggesting high reliability.

The statistics show that sprinklers are very effective in containing the fire, as would be expected. With sprinklers present, whether they operated or not, 60% of fires were confined to the object of origin whereas without sprinklers, the figure is 44%. With sprinklers present, 94% of fires do not spread beyond the room of fire origin, whilst without sprinklers the figure is 75%. Another way of expressing these figures is to note that with sprinklers not present, 22% of fires cause damage beyond the room of fire origin, but with sprinklers present this reduced to 6%—a fourfold reduction.

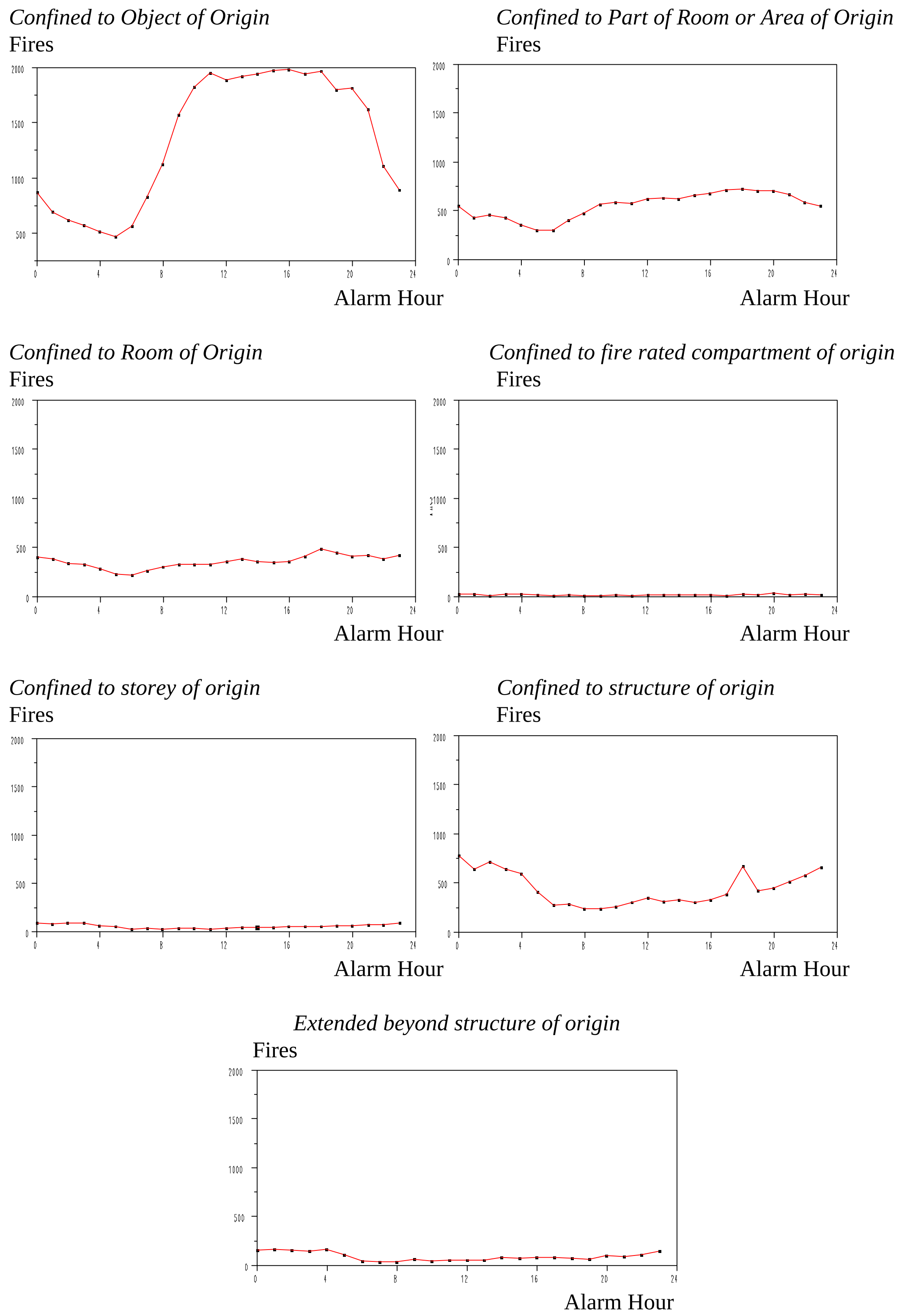


FIGURE 4.1 FIRES FOR EACH EXTENT OF FLAME DAMAGE BY ALARM HOUR

An analysis of the USA retail data in [8] indicates that if sprinklers were present at all of the retail fires then the number of fatalities and total property loss would be reduced to about one third of the actual values. It is likely that these figures substantially underestimate the real value of sprinklers due to the fact that sprinklers are *required* in most larger buildings and the potential damage and loss of life associated with an unsprinklered fire in such buildings could be very substantial.

4.6 CONCLUSIONS

The statistical study has demonstrated that high levels of fire safety are achieved in shopping centres, compared for example to residential occupancies. It has also set the value of fire safety systems in context, showing that the presence of fire-safety systems such as sprinklers has a significant impact on the civilian and fire-fighter fatality rates.

The clear message is that the risk to life can be reduced significantly if the fire is kept small. The role of sprinklers, detectors, structure, and fire fighters, in achieving this objective, is considered in the following chapters of this report.

5. SURVEY OF SHOPPING CENTRES

As part of this 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. The following aspects were studied from a fire-safety perspective:

- *construction details*—influence on limiting fire spread and growth
- *quantity and distribution of combustibles*—influence on fire development and spread
- *population characteristics*—affects the likelihood of fire detection and conversely, the number of injuries and deaths
- *exit details and construction*—including spacing and the effect of long term use and operation
- *sprinkler systems*—including maintenance and management aspects
- *smoke control systems*—including maintenance and management aspects
- *fire warden system and evacuation drills*
- *fire brigade facilities*
- *detection and alarm*
- *management policies*

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 New South Wales. The former centre had a gross retail area of 58,000 m^2 having a department store with a rise in storey of 4 at one end of a two storey mall and was considered to be representative of a large modern shopping centre. The latter buildings had rise in storey 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. Information on the following matters was sought during the visits:

- fire incidents and procedures
- practices and frequency of refurbishment and leasing of retail outlets to new tenants
- general observations on construction— eg. wall height and construction, ceiling construction.
- major modifications to building
- general observation of stores with particular reference to the quantity and layout of combustibles
- observation of reserve areas in major stores—extent of these areas, fire load and housekeeping

- combustibles in mall areas including those associated with festive seasons
- maintenance of fire-safety systems—in this report this is taken as the process whereby the performance of an item of equipment is assured provided that item has not been taken out of service.
- management of fire-safety systems—this term should be taken as referring to the process of managing an item of equipment assuming that it is maintained[5].
- fire-isolated passages
- evacuations strategies and drills

A summary of the findings from these visits and of the data obtained is given in [5] and is used as input to the following chapters.

5 Thus a sprinkler system may be well maintained (eg. pumps, valves etc.) but poor management will allow the system to be taken out of service for longer periods of time than is really necessary.

6. FIRE TESTS

6.1 INTRODUCTION

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. The results of the tests are reported in detail in [11] and a videotape is available.

6.2 TEST PROGRAM

6.2.1 SITUATIONS TESTED

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

Two tests were conducted to simulate a fire in a toy store and two to simulate fire in the storage area of a shoe shop. These situations were chosen because they were considered to be representative of worst case scenarios as they involved substantially non-cellulosic material stored in a shelved arrangement. The presence of shelving means that the fire is likely to grow more rapidly and that it may interfere with the application of water to the seat of the fire, in the case of the sprinklered situations. Both sprinklered and unsprinklered situations were considered. Again the unsprinklered tests were considered to be representative of the fastest growing fires due to the type and arrangement of combustibles.

A series of five sprinklered fire tests was also conducted to look at the smoke generated during sprinklered fires in clothing stores. This was considered important as clothing and the like constitute a high proportion of the floor area of a modern shopping centre.

Finally, two sprinklered tests were conducted to investigate the smoke generated in a sprinklered book shop/newsagent fire. These tests were conducted to study the amount of smoke developed where there were predominantly cellulosic combustibles.

6.2.2 TEST DETAILS

The tests were conducted in the "Burn Hall" at the Scientific Services Laboratories (SSL), Port Melbourne. This building was chosen for its size with the main part of the building, in which the test structure was housed, having a volume of 12,500m^3 and a maximum height of 9m. There is no designed venting in the building except for small gaps at roof junctions and around roller doors at either end. These gaps were estimated to be equivalent to a 250mm wide opening along the full length of the building (55.2m). For the purpose of these tests, a steel test structure was constructed in the centre of the building to act as a floor above the combustibles.

The set up of the test structure for each test was as follows:

- *Tests 1 and 2 ("toy shop tests")* —The test set up area was positioned centrally in the test structure as shown in Figure 6.1. This was done to simulate a part of the toy display area within a large store. No walls were erected around the test area.

- *Tests 3 and 4 ("shoe shop tests")* —Steel walls were placed around the test set up to simulate a typical shoe storage area, such as that which may be located at the back of a specialty or a major store. The walls were 3 m high on three sides and full height on the South side to represent an external wall (Figure 6.2). A 2 m × 2 m opening was positioned on the North wall to represent a doorway leading into the storage area.
- *Tests 5 to 11 ("clothing" and "book shop tests")* —3 m high steel stud walls were placed around the test set up area and a suspended plasterboard ceiling was erected over the area to simulate a small specialty shop (Figures 6.3 and 6.4). A 2 m wide × 2.4 m high opening was positioned on the North wall to represent a doorway.

The sprinklers spacing and water supply provided for these tests was representative of an Ordinary Hazard III system.

The following measurements were taken during the tests:

- Air and steel (where appropriate) temperatures.
- Air temperatures at the sprinkler head locations.
- Air temperatures at various heights within the burn hall.
- Visibility of targets located at various heights within the burn hall.
- Smoke obscuration at various heights within the burn hall.
- Mass loss (Tests 1-4 only).
- Radiation levels.
- Times for sprinkler head activation.

6.3 TEST OBSERVATIONS

The following observations are made in relation to each of the tests:

Test 1 *Sprinklered Toy Shop* (see Figure 6.5)
This fire is probably representative of one of the most severe sprinklered fires, in terms of the quantity of smoke produced. This was due to the combination of predominantly plastic combustibles arranged in shelving, the absence of a ceiling, and the location of sprinkler heads away from the seat of the fire. Sufficient water was not able to get to the seat of the fire and the fire continued to burn along the shelving. Air entrainment into the hot smoke was *primarily* from the action of the sprinklers and this resulted in a substantial increase in the volume of smoke, although at a lower concentration. The effect of the edges of the test structure on air entrainment was considered to be small. It was possible to stand in the burn hall for the majority of the test. The building was evacuated when smoke descended to about 1.5 m from the floor after 12 minutes.

FIGURE 6.1 TEST SET-UP — TOY SHOP

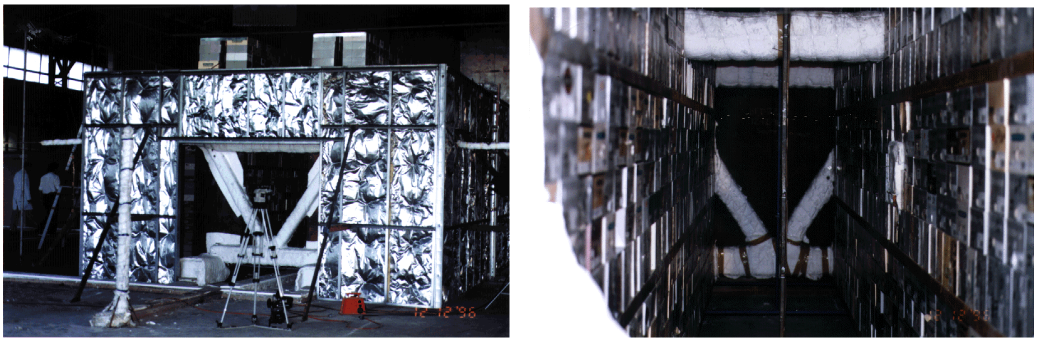


FIGURE 6.2 TEST SET-UP — SHOE STORAGE

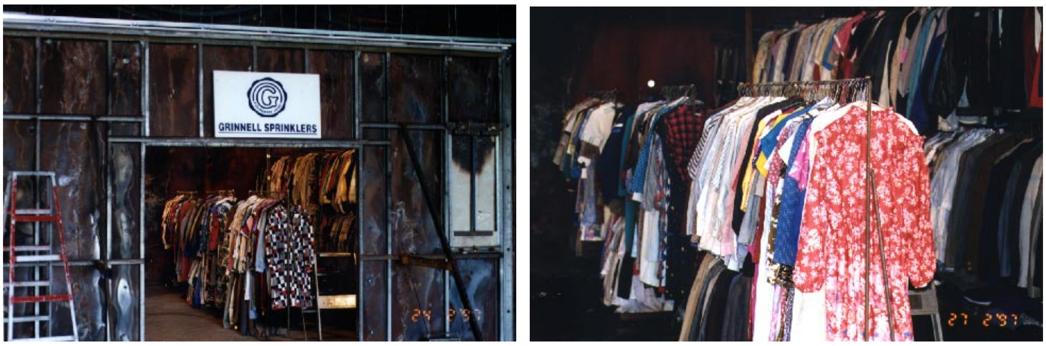


FIGURE 6.3 TEST SET-UP — CLOTHING SHOP

FIGURE 6.4 TEST SET-UP — BOOK SHOP

Shortly *after* sprinkler activation (one sprinkler head), the temperature of the air at the sprinkler heads dropped to less than 100°C—the result of one sprinkler head activating. At the highest part of the burn hall (representative of the "hot layer" away from the immediate fire location) the air temperatures were less than 40°C.

The temperatures of the light steel members located directly above the fire were less then 60°C.

Fire spread to the other rack did not occur and the measured radiation at this shelf reached a maximum of 6.6 kW/m^2.

Test 2 *Unsprinklered Toy Shop* (see Figure 6.6)

This fire is representative of one of the most severe unsprinklered fires, in terms of the quantity and rate of smoke production, and in terms of the air temperatures associated with the fire. As with the previous test, this was due to the combination of predominantly plastic combustibles arranged in shelving such that "vertical" surfaces were created which greatly increased the rate of fire growth. The peak rate of heat release is estimated as 25 MW.

In the vicinity of the test structure, the air temperatures at the soffit reached a maximum of 1200°C and the steel temperatures reached a maximum of about 950°C. Unfortunately data associated with the latter part of this test was lost and it is not certain whether higher temperatures were reached but it appears unlikely. Extensive spalling of the ground floor slab on which the test structure was supported occurred.

The temperature of the air at the highest level within the burn hall reached a recorded maximum of 320°C.

It was possible to remain within the burn hall during the test until approximately 7 minutes had elapsed at which point the smoke layer began to descend rapidly to the floor.

Test 3 *Sprinklered Shoe Storage* (Figure 6.7)

In this test the shelves were higher and closer spaced than for Test 1, and although the arrangement was acceptable under AS2118, it was clear from the spray patterns that little water would be expected to reach the seat of the fire.

Interestingly, in both this test and Test 4, it took a very considerable time for the fire to develop due to the relatively compact nature of the combustibles. In the case of such a fire starting in a shopping centre, it is most likely that the fire would be noticed by an occupant or detected by a smoke detector, before it built to the size required to activate the sprinklers. Four sprinkler heads activated and the temperature of the air in the vicinity of the sprinklers reached around 200-250°C with the temperature of the steel members reaching a temperature of between 85-240°C. At the highest part of the burn hall the air temperatures reached a maximum of 145°C.

FIGURE 6.5 TEST 1 SPRINKLERED TOY SHOP

FIGURE 6.6 TEST 2 UNSPRINKLERED TOY SHOP

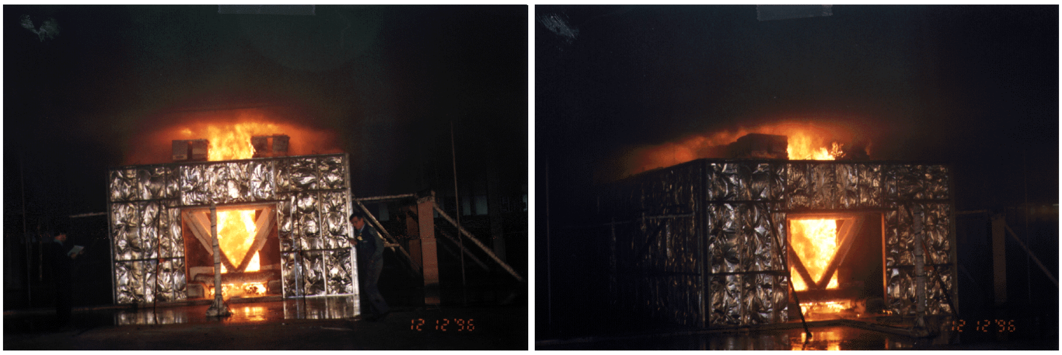


FIGURE 6.7 TEST 3 SPRINKLERED SHOE STORAGE

FIGURE 6.8 TEST 4 UNSPRINKLERED SHOE STORAGE

It appears from these test results, that in a real sprinklered situation, many more than the four sprinkler heads would have been activated and this may have resulted in the sprinkler system being “overwhelmed”. If sprinkler heads had been positioned between the racks, the fire would have been rapidly suppressed. It would therefore appear, from a property protection viewpoint, that sprinkler positions and type should be appropriately for the racking situation.

Test 4 *Unsprinklered Shoe Storage* (Figure 6.8)

As noted for Test 3, this fire took a considerable time to develop and its presence would almost certainly have been noticed if the building was occupied. Once again, because of the significant quantity of non-cellulosic combustibles involved, this fire became one of the most severe unsprinklered fires likely to be encountered in a retail situation. The fire achieved a peak rate of heat release of 40 MW.

In the vicinity of the test structure, the air temperatures at the soffit reached a maximum of 1320°C and the steel temperatures a maximum of 1250°C. These temperatures and the consequent effect on the structural steel resulted in substantial deformation of the floor members. However, the floor continued to support the self weight of the floor through catenary action enabled by presence of larger cooler beams at the exterior of the test structure.

The ground floor slab on which the test structure was supported suffered heavy spalling with pitting close to 50 mm deep.

The air temperature at the highest level within the burn hall reached a maximum of 360°C.

It was possible to remain within the burn hall during the test until approximately 34 minutes had elapsed at which point the smoke layer began to descend rapidly to the floor.

Tests 5 - 9 Sprinklered Clothing Shop (Figure 6.9)

A ceiling was present for all of these tests and this generally resulted in faster activation of the sprinklers due to the sprinklers being closer to the fire and the fact that the hot gases were directed on to the heads. The clothing burned vigorously, but once the sprinklers activated, the fires were rapidly controlled and reduced in intensity. Nevertheless, the clothing tended to shield the fire from the sprinklers so that the fire was not totally extinguished. The reality of this point was demonstrated by the fact that once the sprinklers were turned off, the fire re-developed, and had to be put out manually or by turning the sprinklers on once again. Care should therefore be exercised in isolating sprinklers before the fire has been fully extinguished or before the fire brigade is in position to finally extinguish the fire.

After activation of the sprinkler heads, the temperature of the air at the sprinkler heads dropped to generally less than 50°C. At the highest part of the burn hall the air temperatures were equal to the ambient temperature.

FIGURE 6.9 TESTS 5-9 SPRINKLERED CLOTHING SHOP

FIGURE 6.10 TESTS 10-11 SPRINKLERED BOOK SHOP

As noted earlier, different forms of sprinklers were made the active heads in each of the tests in order to determine whether this had a significant impact on the level of smoke. It is difficult to see any significant difference in the level of smoke associated with each test. This is primarily due to the fact that the most important factor affecting the quantity of smoke produced is the amount of shielding offered to or by the combustibles. The painted flush plates were the slowest to activate but there did not appear to be any difference in response time between the non-painted and painted normal response heads.

The smoke developed in these tests contained substantial steam and was sometimes buoyant and sometimes remained sporadically at ground level. The smoke outside the test enclosure was transparent and did not present a threat to the occupants within the test building.

Tests 10-11 Sprinklered Book Shop (Figure 6.10)

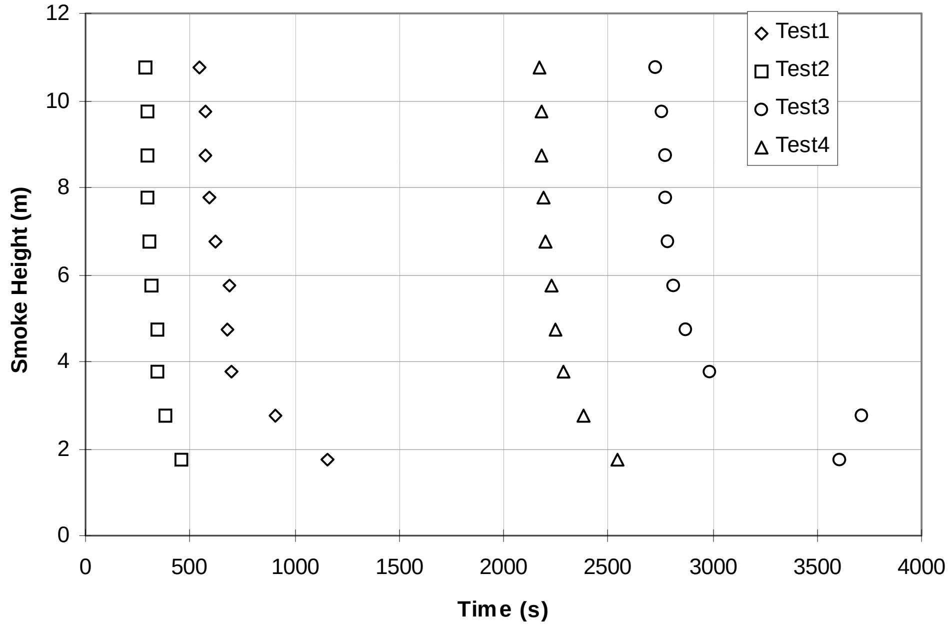
In both of these tests it took considerable time for the fire to build to a sufficient intensity for the sprinklers to be activated. It is believed that such fires would most likely be detected by the occupants and extinguished before the sprinkler activated. A ceiling was also present for these tests. Once the sprinklers activated, the fires were rapidly controlled and reduced in intensity being extinguished by the sprinklers.

These tests (especially Test 11) allowed the development of a distinct hot smoke layer within the test enclosure due to the lengthy period before activation of the heads.

Shortly *after* activation of the sprinkler heads, the temperature of the air at the sprinkler heads dropped to less than 50°C. At the highest part of the burn hall the air temperatures were equal to the ambient temperature.

The smoke developed in these tests was whiter than in Tests 5 to 9 and contained substantial steam. The smoke outside the test enclosure was transparent and did not prevent a threat to the occupants within the test building. The painted flush plate sprinkler (Test 11) took longer to activate that the normal sprinkler head but this did not appear to have a significant impact on the amount of smoke generated.

It is interesting to compare the various tests in as far as the rate of smoke production is concerned. The plots of the smoke layer descent in the various tests are shown in Figure 6.11. These test data are considered further in Chapter 11.



FIGURES 6.11 SMOKE LAYER HEIGHT VS TIME RESULTS

7. SPRINKLER EFFECTIVENESS

7.1 INTRODUCTION

As a general rule, shopping centre management has the perception that sprinklers are provided primarily for property protection or insurance purposes—rather than for life safety. This perception possibly comes from the insurance industry who (fortunately) attempt to exercise some control over sprinkler isolation in these buildings. In reality, as will be shown in this report, sprinklers have an essential role to play for both life safety and property protection.

The benefits of a functioning sprinkler system have been demonstrated from the fire tests conducted as part of this project and the difference in the size of fires associated with the sprinklered and unsprinklered situations. The anecdotal evidence presented in Chapter 3 testifies to the value of sprinkler systems in providing life safety and property protection, as does the statistical evidence given in [8] and summarised in Chapter 4.

The purpose of this chapter of the report is to consider both the *efficacy* and *reliability* of sprinkler systems. These terms are each represented numerically by a number between 0 and 1. Sprinkler *efficacy* is defined here as the ability of the sprinkler system to function in accordance with AS 2118 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. Sprinkler *effectiveness* is defined as:

$$effectiveness = reliability \times efficacy$$

Statistical data from fire incident returns provide one basis for gauging the reliability and efficacy of sprinkler systems. However, these data give an historical overview which will include the effects of past practices and regulations—and therefore should not be assumed to necessarily apply to modern shopping centres with improved design and management practices.

7.2 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.

The sprinkler system required for shopping centre buildings is an ORDINARY HAZARD III (OH III) system and the sprinkler spacing and water delivery rates are considered to give a high level of protection to retail buildings. 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.

Fire tests described in Chapter 5 considered two of these situations. In one of these tests (Test 3) it was recognised that the location of sprinkler heads was inadequate given the height and nature of the combustibles. Better positioning of the heads would have resulted in rapid control of the fire.

☛ *In the case of high fire load areas such as shoe storage, where combustibles are stored in high racks that will interfere significantly with the application of water to the fire, sprinklers heads should be relocated or added to ensure that heads are located between the racks. Specific guidelines need to be developed.*

There is little value in incorporating a sprinkler system into a building if it is not commensurate with the hazard.

Approximately 33% of the gross sales area of a shopping centre building is occupied by clothing or fabric shops. Tests 5-9 (see Chapter 5) demonstrated the speed at which the fire can grow in clothing stores and the efficacy of sprinklers in controlling these situations. Various types of sprinkler heads were considered—normal response, fast response, flush plate, painted normal response, and painted flush plates. As discussed previously, *painted flush plates were the slowest to respond but still able to rapidly control the fire. Painting the sprinkler heads appeared to have no effect on sprinkler performance*—although this is not a practice that should be encouraged.

In the past, many retail complexes were partially or inappropriately sprinklered. This has been certainly the case in the USA. In Australia, for example, some shopping arcades formerly incorporated sprinklers within the arcade or mall and not within the shops. Another variation was to incorporate two sprinkler heads at the front of the shops as well as within the arcade. In other situations, ceiling or floor spaces were not sprinklered and sometimes were constructed using combustible materials; or whole sections of the building were not sprinklered. Examples of some of these situations are given in [7].

☛ *Subject to the better positioning of sprinkler heads in relation to higher racking, and the absence of partial sprinklering, except as outlined in Section 7.4, the efficacy of sprinklers can be taken as effectively 100%. Otherwise, based on the analysis of statistical data presented in Appendix 7.1, a value of 97.5% may be adopted (cf. 93% for the USA).*

7.3 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. Such an evaluation is presented in Appendix 7.2 where 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.*

☞ *Management of major modifications to a building (as opposed to specialty shop upgrades) should be started at the design and planning stage by:*

- *ensuring that the new construction has a separate sprinkler system if it is large enough, or*
- *constructing the sprinkler pipe work in the new part of the building in such a way that it can be connected to the old system in a short time (within a day).*
- *Some other strategy to ensure that the occupied parts of the building are not isolated during the construction phase.*

Based on the analysis presented in Appendix 7.1, the current average reliability for sprinklered buildings in NSW (typical of Australian buildings) is 98%. The corresponding value for the USA is 93.5%.

☞ According to Appendix 7.2, *if the sprinkler system is soundly managed, the following average values of reliability can be adopted:*

Sprinkler zones associated with specialty shops	*98.50%*
Sprinkler zones associated with major stores	*99.50%*

These values of reliability assume that there are *separate sprinkler zones for major stores and specialty shop areas*. This is absolutely essential, as otherwise the reliability of the systems associated with major stores will be reduced.

☞ *Sound management of the sprinkler system includes:*

- *using primarily one company for sprinkler isolations.*
- *re-instatement of the system at the completion of work each day.*
- *an approval system in place which requires written permission from management before isolation can take place and a statement as to the length of isolation (which must generally be less than one day)*
- *a requirement for the contractor to sign-off after completion of the work.*
- *penalties on contractors for failure to comply with the above.*

In undertaking modifications to major stores where part of the floor requires sprinkler isolation and the rest is involved in trading or contains significant combustibles, it is important that such work is planned and undertaken so that the isolation of sprinklers in the latter part of the floor is minimised. This can be achieved by judicious plugging off sprinklers in work areas while allowing active heads to remain in the parts of the floor where combustibles are located.

☞ *The use of monitored valves is an essential additional measure to guard against accidental or unintended valve isolation.*

The use of monitored valves will support sound management as notification of isolation is required and time of re-instatement just prior to the event. If the system is not re-instated within the prescribed time period, the fire brigade will arrive at the building to investigate the situation.

7.4 MALL AND ATRIUM ROOF SPRINKLERS

As observed in Section 2.6.3, the BCA requires that if the roof of an atrium does not have an FRL then it must be sprinklered if the distance from various parts of the atrium and the roof exceed the limits given in Figure 8.4 of [4]. Furthermore, AS2118 would appear to require sprinklering of the roof for mall situations. This issue is considered in Appendix 7.3.

☛ *It is concluded that sprinklers will not be effective at heights greater than 10 m above the closest floor level where combustibles are located, and therefore such sprinklers are not required.*

☛ *It is recommended that other strategies be developed for handling fires within malls and atrium spaces.*

Options include specific sprinklering of concessions (see glossary of terms) within the mall or spacing of concessions to minimise the likelihood of fire spread.

7.5 SPRINKLER PRACTICES

Two issues relating to sprinkler practices which were identified during the study of shopping centres are: (a) sometimes a sprinkler head has been removed by a fitter who thought that the head was connected to an isolated system—only to find that the head was connected to an active system. An occurrence such as this, which is common at the borders of zones, can result in:

(i) Substantial water damage[6]

(ii) A call to the fire brigade—the activation of a head results in an alarm signal to the fire brigade. This may result in significant charges for a "false alarm"[7].

The above consequences mean that sprinkler contractors sometimes tend to "play it safe" by isolating as many valves as might be required to ensure that the above does not happen. *The effect of this practice is that larger sections of the centre may be isolated than is necessary. This, in turn, has a detrimental effect on sprinkler reliability.*

A high level of sprinkler reliability is important and any practical means to improve this should be pursued. Possible solutions are:

(i) Insisting that block diagrams giving sprinkler locations are drawn, updated and displayed at the appropriate valve.

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6 Damage is typically up to $30k in lost stock and clean-up costs.

7 These charges can be up to $4000 and are carried by the sprinkler contractor who is working in a very competitive environment.

(ii) Getting fire brigade policy changed such that there is no charge for "false alarms" in shopping centres where the fire-safety systems are subject to an *appropriate maintenance program*.

(b) Due to the frequency of tenancy fit-outs, the reliability of sprinklers in specialty shops is lower than for major stores. Sprinkler reliability in zones for specialty shops could be improved by the incorporation of additional monitored valves such that parts of a zone can be isolated. It appears that this practice is economically justifiable[8] if up to ten specialty shops or up to 120 heads were connected to a subsidiary valve. Each valve would be required to:

- be located on the floor and accessible from the mall.
- be monitored.
- have updated block diagrams giving sprinkler head locations.
- have means to drain water from this part of the system.

The incorporation of the above system in a shopping centre building with a sound management system would allow the average sprinkler reliability in specialty shop areas to be increased to 99.5%.

☞ *Sprinkler protection is critical for high levels of fire safety.*

8 Each additional valve and associated hardware with connection to the FIP panel will cost money. However, there are substantial financial benefits of such a system as the time to drain the particular section of the zone will be much faster than draining the whole zone, and this will result in substantial savings of contractor charges on an ongoing basis.

8. FIRE SCENARIOS

8.1 INTRODUCTION

Fire may occur at any time and in any part of a building. A proper assessment of fire safety in buildings must consider the relevant range of possible fire scenarios.

The purpose of this chapter of the report is to give a description of the relevant fire scenarios, their broad characteristics, and their likelihood of occurrence. A fire may have an effect on the occupants—but the reverse can also be true. There is therefore, an *interaction* between the fire and the occupants. The form of this interaction is considered in detail in Chapters 10 and 11, and in the case of the fire brigade, in Chapter 14.

8.2 FIRE IGNITION FACTORS

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 maintenance 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[9].

According to [8], 36% of all reported fires 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.

☛ *It follows that proper maintenance of equipment with routine checking for "hot spots" associated with switchboards and equipment is likely to have a positive influence on reducing the incidence of fire starts*[10]—certainly when compared with the general run of retail buildings in Australia or the USA. This matter is considered further in Section 8.4.2.

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[11] [16].

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[9] 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.

[10] This practice already occurs in some major shopping centres.

[11] A Swiss organisation responsible for operation of the fire brigades, building insurance, and building regulations in the Canton of Bern in Switzerland

8.3 STATISTICAL OVERVIEW

In presenting an overview of fire scenarios, it is convenient to divide them as illustrated in Figure 8.1. Thus fires may be grouped on the basis of:

- whether the fire brigade was called or not.
- the time of day at which the fire occurred.
- the location of the fire, and
- the size of the fire.

There are 28 *fire scenario groups*. Each fire scenario group represents a set of fires which have similar but not identical characteristics. The breakdown of fires into the various groups is illustrated in Figure 8.1 for a typical shopping centre with a combination of specialty shops and major stores. The fire scenario groups are now considered in detail.

8.3.1 FIRES NOT ATTENDED BY THE FIRE BRIGADE (F_{SG1})

There are many small fires that are not attended by the fire brigade and are self extinguished[12] or extinguished by the occupants. These are denoted as F_{SG1}—fire scenario group no. 1. As these fires are not attended by the brigade there are no corresponding fire incident reports. However, the existence of such fires is supported by anecdotal evidence [17], from data for particular buildings on the use of fire extinguishers versus the number of times that the fire brigade have been summoned; and from survey data associated with particular buildings. Firm data on this matter has been obtained by the GVB/AIB. This organisation maintains excellent records of both fire brigade call-outs and insurance claims. Their records indicate that for every three insurance claims relating to fire there is only one call-out to the fire brigade. Furthermore, it is known that there are many additional fires for which no insurance claim is made and the ratio of actual fires to those resulting in a call-out to the fire brigade is estimated as being between 5 and 10. In this report it is assumed that four out of five fires do not result in a call to the brigade. This means that 80% of fire starts will *not* result in brigade attendance.

8.3.2 FIRES ATTENDED BY THE FIRE BRIGADE (F_{SG2} – F_{SG28})

8.3.2.1 Background

a) Effect of Time of Day

USA statistics indicate that 70.4% of fires occur during major trading hours which are taken as 8am to 10pm. This period of time is hereafter referenced as *day* and is of primary concern with respect to life safety. Fires which occur outside of the major trading hours are considered to occur at *night* (10pm to 8am) and are of greater interest for property protection.

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[12] The expression "self extinguished" should be taken to mean that a fire ceases to burn without assistance from fire fighting measures.

FIGURE 8.1 FIRE SCENARIOS

b) *Effect of Location*

Fires can be divided according to location within the building. The fire incident reports completed by the fire brigade recognise the following possible locations for a fire start—*means of egress, assembly sales areas, function areas (mainly residential), function areas (commercial), storage areas, service facilities, service/equipment areas, structural areas, transportation/vehicle areas* and *others*.

Function areas (residential) include sleeping areas, canteens, lunch rooms, washrooms, locker rooms and kitchens. Some of these areas are relevant to modern shopping centres whilst sleeping accommodation is generally not. In many ways, function areas could be considered to be part of sales areas as they are often in very close proximity, and the associated combustibles will not be too different to those within the sales areas. The same is true for *function areas (commercial).* All of these areas are combined to form a new grouping: *assembly sales/other* area for the purpose of this study. *Transportation areas* refers to vehicles and parts of vehicles and is not relevant. It is therefore ignored in the following discussion.

Service Facilities include such things as elevators, escalators, and ducts. They also cover display windows. *Service, Equipment Areas* include pump rooms, refrigeration rooms/areas, heating equipment room or area, electrical switchgear rooms/areas. *Structural Areas*, as they apply to shopping centre buildings, refer to crawl and ceiling spaces, exterior roof and wall surfaces, wall cavities, and awnings.

The above locations of fire origin can be re-grouped into the following:

- means of egress
- assembly sales/other
- service facilities
- service, equipment areas
- structural areas
- storage areas

Based on USA fire statistics, this grouping gives rise to Table 8.1.

TABLE 8.1 OCCURRENCE OF FIRES BY LOCATION

Location	*% of total fires*	
of Fire Start	*day †*	*night*
means of egress	2.6	4.7
sales/other	36.0	33.7
service facilities	3.9	2.1
service/equipment areas	12.3	7.2
structural areas	27.4	29.3
storage areas	17.7	23.0

† day is taken as between 8 am and 10 pm

c) Linkage to Sales/Other Areas

Areas within the building such as *storage areas* and *structural areas* are separate from, but closely linked to sales/other areas—and more particularly to major stores and specialty shops—for the following reasons:

- these areas are within the same part of the building
- fire safety systems (eg. sprinklers, detectors) are usually common as far as zoning is concerned.
- activities are closely related to those in sales/other areas.

According to [5], approximately 40% of the gross lettable retail area of a typical shopping centre is occupied by specialty shops, with the remainder being occupied by major stores. It is reasonable in the case of sales/other areas to assume that the likelihood of a fire start in either a specialty or major store is proportional to the relative floor area of these areas. About 8% of the floor area of a major store is occupied by storage areas [5].

d) Classes of Fire

Fires can be conveniently grouped into 3 broad classes according to their size (see Figure 8.1):

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

These classes of fire are now considered in relation to the various fire scenario groups.

8.3.2.2 Fires Kept Small without Sprinklers (C1)

The fire scenario groups F_{SG2}, F_{SG5}, F_{SG7}, F_{SG11}, F_{SG14}, F_{SG17}, F_{SG20}, F_{SG23}, F_{SG26} are associated with this class of fire. The common characteristic is that these fires are all small having been limited to the area of fire origin by means of self-extinguishment or occupant and/or brigade intervention—but without the assistance of sprinklers.

Based on USA fire statistics, the percentages of fires limited to the area of fire origin for each fire start location is given in Table 8.2 for unsprinklered buildings.

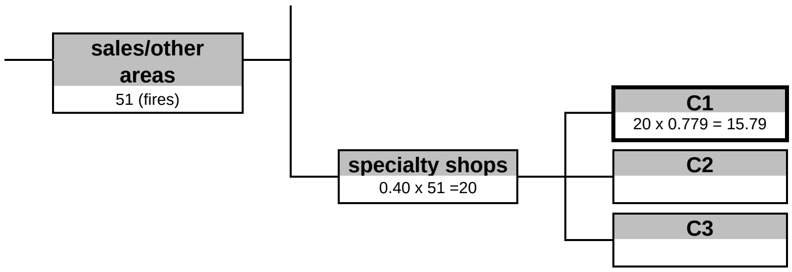
TABLE 8.2 EXTENT OF FLAME DAMAGE FOR EACH LOCATION

Location of Fire Start	*% of fires limited to area of fire origin*	
	day †	*night*
sales/other	77.9	52.1
service facilities	91.2	74.3
service/equipment areas	77.3	54.3
structural areas	82.6	62.0
means of egress	84.1	62.6
storage areas	67.0	44.3

† day is taken as the between 8 am and 10 pm

These are fires for which it is assumed that flashover has not occurred. In this report, flashover is considered to be “the rapid transition from a localised fire to the combustion of all exposed surfaces within a room or compartment” [3].

With reference to Figure 8.1, the number of C1 fires associated with a particular location (and type of store if that is appropriate) can be determined using the figures given in Table 8.2 and the percentage floor areas associated with specialty and major stores (see Section 8.3.2.1(c)). This is illustrated below for the sales/other location:



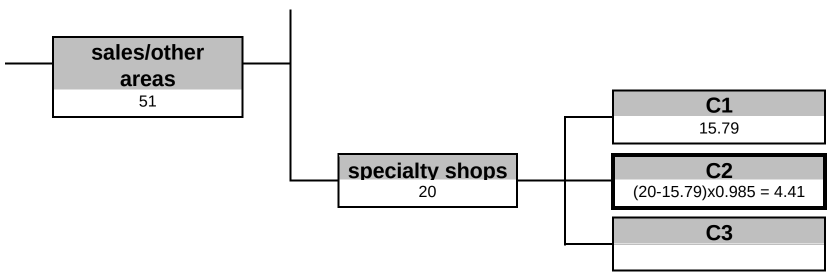
(NB: This is a detail of Figure 8.2)

8.3.2.3 Fires which are Controlled by Sprinklers (C2)

The addition of a sprinkler system will have a very significant effect on *further* reducing the number of fires that extend beyond the area of fire origin. The resulting fires are taken as fire scenario groups F_{SG3}, F_{SG6}, F_{SG9}, F_{SG12}, F_{SG15}, F_{SG18}, F_{SG21}, F_{SG24}, F_{SG27} as shown in Figure 8.1.

These fires will all have low heat release rates, being relatively small fires but may differ markedly in their smoke-generating capacity depending on the position of the sprinkler heads and the orientation and types of combustibles. Thus, when considering the issue of smoke management, it will be important to understand the *range* of fires that exist within each fire scenario *group*. This task is undertaken in Chapter 11.

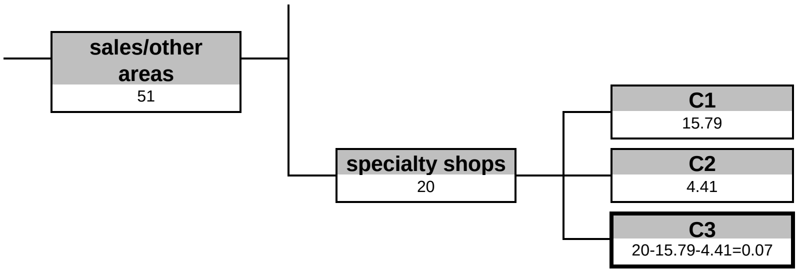
As noted in Section 6.3 the effectiveness of sprinklers is different depending on whether a major store or specialty shop is being considered but also upon the level of system management. Once the effectiveness of the relevant sprinkler system is known, the percentage of fires associated with each fire scenario group can be determined. This is illustrated for the above example assuming a sprinkler effectiveness of 98.5%. Detailed calculations for various levels of sprinkler effectiveness are presented in Section 8.4.



(NB: This is a detail of Figure 8.2)

8.3.2.4 Fires not Limited to Area of Fire Origin (C3)

These fires (ie. F_{SG4}, F_{SG7}, F_{SG10}, F_{SG13}, F_{SG16}, F_{SG19}, F_{SG22}, F_{SG25}, F_{SG28}) are the fires that are potentially severe, as in many cases, flashover may have occurred. Such fires can only eventuate when the sprinkler system has failed and may well present a significant threat to the occupants. The number of these fires is determined as shown below:



(NB: This is a detail of Figure 8.2)

According to the USA statistics for unsprinklered buildings, the following extent of flame damage statistics apply for fires where the *damage has extended beyond the area of fire origin*.

TABLE 8.3 FIRES WHERE EXTENT OF FLAME DAMAGE EXCEEDS AREA OF FIRE ORIGIN

Fire Scenario Group	*day †*		*night*	
	% confined to room (C3-1)	*% beyond room (C3-2)*	*% confined to room (C3-1)*	*% beyond room (C3-2)*
F_{SG4}	34	66	24.4	75.6
F_{SG7}	34	66	24.4	75.6
F_{SG10}	17.6	82.4	10.2	89.8
F_{SG13}	17.6	82.4	10.2	89.8
F_{SG16}	33	67	24.8	75.2
F_{SG19}	33	67	24.8	75.2
F_{SG22}	38.8	61.2	24.2	75.8
F_{SG25}	34	66	45.7	54.3
F_{SG28}	17.5	82.5	12.9	87.1

† day is taken as the between 8 am and 10 pm

In this table, the fires that are confined to the room of fire origin are denoted as C3-1 fires. They are considered to be more severe than those confined to the *area of fire origin* but not as severe as those where flame damage has extended beyond the room of fire origin (ie. C3-2 fires). The data in the table are now used to consider the fire scenario groups in more detail.

F_{SG4} — Major stores not only have extensive sales areas but also numerous rooms (other than storage areas or service equipment rooms) for use by the staff—these are *function areas*— and about 60% of fires in sales/other areas occur in such rooms[13]. It is

13 As determined from detailed study of statistics.

reasonable to assume that the C3-1 fires (which according to the Table 8.3 constitute up to 34% of the C3 fires), in the main, have originated in such rooms. The fire may not have reached flashover, or if it had, the resulting fire was not sufficiently intense to result in spread outside the room or was contained by appropriate fire fighting.

The C3-2 fires (which according to Table 8.3 constitute up to 66% of the C3 fires), will be those that have originated within function areas and sales areas. It can be assumed that $\frac{(60-34)\times 100}{66} = 40\%$ of these fires will have originated in function areas and the remainder in the sales area.

F_{SG7} — In this case, it is likely that the C3-1 fires are very close to flashover or have *just* achieved flashover[14], but the fire is restricted to the room by successful fire fighting.

The C3-2 fires, on the other hand, are where the fire has spread to adjacent occupancies and is where a flashover fire is being experienced in the specialty shop. Spread is most likely to be via the ceiling spacing but could also be laterally at the front of the store, and possibly eventually, across the mall due to high levels of radiation.

F_{SG10} & F_{SG13} — Only a few C3-1 fires are associated with structural areas and this indicates the difficulties experienced with detecting and fighting fires in these areas—most of ending up as big fires. A fire commencing in these areas will most likely spread downwards (given sufficient time) and will eventually result in the C3-1 and C3-2 fires associated with F_{SG4} and F_{SG7} fire scenarios. The time taken to reach the same severity will be *longer* due to the spread and development which must first take place in the structural areas.

F_{SG16} — Storage areas are specific rooms in major stores. It is argued that the C3-1 fires in such rooms have been contained by successful fire fighting. These may include some flashover fires—but these fires would not have been sufficiently intense to result in fire spread outside the room.

The C3-2 fires, on the other hand, will be severe and spread beyond the storage room. Once again, these fires will eventually become similar to those experienced in the sales areas.

F_{SG19} — Storage areas are usually specific rooms at the rear of a specialty shop. Again, it is argued that the C3-1 fires in such rooms have been contained by successful fire fighting. These may include some flashover fires—but these fires would not have been sufficiently intense to result in fire spread outside the room into the main part of the shop.

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[14] The conditions associated with a flashover fire are such that spread may take place to adjacent stores unless fire-fighting occurs close to the time of flashover.

The C3-2 fires, on the other hand, will be flashover fires which spread into the rest of the shop and perhaps beyond. These fires become very similar to those within the sales areas of these shops.

*FSG*22 — These include plant and equipment which is usually located in a room. The C3-1 fires are not likely to be very severe (due to a general lack of combustibles in these areas) and even if flashover has occurred, it will be able to be contained by fire fighting.

The C3-2 fires are where flashover has occurred, fire-fighting has not been present or successful, and where the fire has spread to the adjacent rooms—most probably sales areas. Thus these fires will eventually become similar to those in the sales areas.

*FSG*25 — This fire scenario group includes fires in elevators, escalators and ducts. Fires which start in an escalator may become significant depending on the materials of construction[15]—but it is difficult to see how modern escalator construction (provided it is principally made from non-combustible construction) could lead to this situation. In the case of lifts, fires have occurred in lift cars and with related apparatus (eg. hydraulic equipment). In modern construction, fires associated with lifts are almost always limited to the lift shaft but are *likely* to be recorded as extending beyond the room of fire origin—simply because the life shaft connects all levels of the building. It is considered that these fires are not severe.

Fires are common in ducts especially in kitchen areas where ducts may contain substantial cooking fat. Furthermore, these ducts usually extend outside of the room through the ceiling space, and it is easy to see how spread can occur to other parts of the building—particularly if there are combustibles within the ceiling space. In other cases the fire within the duct will spread back into the room and this may result in fire spread across the room, and if flashover occurs, beyond the room.

Based on the above discussion, it is conservatively assumed that all *FSG*25 fires are associated with ducting.

*FSG*28 — These fires do *not*, in the main, refer to fires originating within mall areas. They refer, more specifically, to fires in stairs and other exit pathways. Most of the fires are classed as spreading beyond the room but perhaps this is because means of egress such as stairs can provide a passage for fire to spread outside the room. The development of such fires is certainly a possibility where combustibles are located below stairs or where the stairs are constructed of combustible construction—but is difficult to see how C3-2 fires could develop within a well managed building[16].

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[15] Escalators incorporating substantial combustibles were associated with the London Underground fire and resulted in substantial flame spread and loss of life.

[16] The storage of combustibles below exit ways is not permitted by the BCA.

The matter of fires originating within a mall is not explicitly covered by the statistical data and is considered separately throughout this report.

8.4 IMPACT OF VARIOUS FACTORS

8.4.1 INTRODUCTION

In general, C1 fires do not present a threat to the occupants. On the other hand, C2 fires may, in some circumstances, generate significant quantities of smoke. This will certainly be the case with C3 fires. For the purpose of smoke management (Chapter 11) and the building structure (Chapter 12), it is important to know the numbers of different types of fires (ie. C1, C2, and C3) that may be associated with the various fire scenarios groups. The number and type of fires will be influenced by many factors including sprinkler effectiveness, combustible construction, etc. These factors are considered in Section 8.4.2.

8.4.2 INFLUENCING FACTORS

The data presented in Section 8.3 for unsprinklered buildings were for shopping complexes in the USA. It is assumed that average levels of equipment monitoring and maintenance (including electrical equipment) took place in these buildings, but that very few had earth leakage residual current protection. Surveillance of areas away from public areas (eg. storage areas) was probably low[17] although high in other areas. Only 15% of these buildings had any form of smoke detection; and even where detection was provided, there was no direct connection between the detector output and the fire brigade[18]. Combustible construction was incorporated in parts of many of these buildings with the structural component or finish being the material ignited in 26% of fires.

The possible impact of various factors on the number of fires in the fire scenario groups is now considered.

i. *Improved Monitoring of Electrical Switchboards*

36% of fires starts are ascribed to electrical causes with 50% of these being associated with electrical distribution equipment. Surveillance of switchboards with temperature sensitive cameras is undertaken in some centres as part of the ongoing maintenance program. It is considered that the presence of such a surveillance program (with associated maintenance) will be effective in reducing the number of fire starts associated with electrical distribution equipment. Information from Europe [18] indicates that such scanning is effective in identifying potential problems. Information from a large Melbourne shopping centre where this practice has occurred for about 7 years, indicates the following:

- larger switchboards are generally not a problem due to their construction and the fact that housekeeping around them is usually sound.

[17] This is also low in Australian buildings.
[18] Direct connection to the brigade is rare in the USA.

- smaller switchboards associated with specialty shops particularly present a problem with poor housekeeping and less robust construction. Annual inspection results in about 20% of switch boards being found to have a potential problem (including poor housekeeping at the board) and modifications are made accordingly.

It is assumed that 50% of electrical distribution fire starts can be eliminated by such a 12 month inspection. That is, fire starts can be reduced by $0.50 \times 0.50 \times 0.36 = 0.09$ or 9% based on the data presented in Section 8.2.

ii. *Earth Leakage Residual Current Protection*

In this case, it is estimated from Swiss data [19] that the introduction of residual current protection will reduce electrical fire starts by 17.5%. Based on the data presented in Section 8.2, the number of fire starts can be reduced by $0.175 \times 0.36 = 0.063$ or 6.3%.

iii. *Non-combustible Construction in Structural Areas*

If non-combustible construction and materials are used in the *Structural Areas* then a greater proportion of fire starts will be confined to the object or area of origin, than is suggested by the figures given in Table 8.2. In this case it is assumed[19] that the percentage of fires limited to the area of fire origin can be increased to: $p + (100 - p) \times 0.75$ where p is the percentage given in Table 8.2 and *0.75* refers to the reduction in fires that have the potential to go beyond the area of fire origin.

iv. *Sprinkler Effectiveness*

As noted in Chapter 7, sprinkler effectiveness depends on many factors including the extent of sprinklering and the level of management. The average values of effectiveness given in Table 8.4 may be used. These values were derived in Appendix 7.2 and should be compared with that for typical USA (0.86) and NSW (0.96) retail buildings (see Appendix 7.1).

The effectiveness of the sprinklers at night is higher because of their greater reliability due to a lesser number of sprinkler isolations.

v. *Smoke Detection and Increased Surveillance*

Smoke detection or increased surveillance of critical areas (particularly storage areas associated with major stores) will not influence the number of fire starts in these areas but rather give an earlier warning than that from the sprinklers. It may therefore prevent a C1 fire becoming a C2 or C3. If the sprinklers have been isolated in this part of the building it is likely that the detection system will also have been isolated. This is not a good practice but is likely to happen: in some cases it is probably unavoidable. Surveillance by means of cameras will certainly help but it is difficult to put a number on the expected improvement. It is not possible, at this stage, to allow for any improvement associated with this factor.

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[19] It is possible to argue that *all* structural fires would remain small if there was no combustible construction. Rather, it is suggested that 75% will remain limited to the area of fire origin.

vi. *Occupant Fire Fighting*

As will be shown in Chapter 10, the occupants of a building have an important role to play in fire-fighting, or in controlling the fire until the brigade arrives. It appears that the provision of sufficient extinguishers with associated training has a major impact on fire safety in these buildings. Improvements in occupant fire fighting are likely to result in even greater limitation of fires to the area or object of origin. This matter is considered further in Chapter 14 and no further allowance for this factor is made below.

TABLE 8.4 VALUES OF SPRINKLER EFFECTIVENESS

		effectiveness					
		day†			*night*		
	management of sprinkler system	*specialty shop*	*major store*	*service facilities service equip.*	*specialty shop*	*major store*	*service facilities service equip.*
(a)	*soundly managed*	0.985	0.995	0.990	0.999	0.999	0.999
(b)	*improved and soundly managed*	0.995	0.995	0.995	0.999	0.999	0.999

Notes:
1. These values compare with the current effectiveness for NSW retail buildings of efficacy x reliability = $0.98 \times 0.985 = 0.96$
2. The effectiveness of the sprinklers at night is a function of the reliability of the water supply - see Appendix 7.2.
3. † day is taken as the time between 8 am and 10 pm

8.4.3 COMBINATIONS OF FACTORS CONSIDERED

In presenting a statistical overview of the various fire scenarios and the impact of the above factors, it is convenient to consider a hypothetical 1,000 fire starts in a building. For a large shopping centre, with a gross lettable floor area of about 75,000 m^2, this corresponds to about 50 years of service life based on the statistics presented in Appendix 8.1.

Various combinations of the factors described in Section 8.4.2 have been considered and are summarised in Table 8.5. The “base” situation does not take advantage of any of the improvements described in the previous section and assumes a sprinkler effectiveness corresponding to a building in the USA having an average effectiveness of $0.93 \times 0.92 = 0.86$. This is an important situation as it allows a direct comparison between Australia and the USA and inferences can be made with respect to the risk to life safety in the two countries.

For each of the above combinations, the numbers of C1, C2 and C3 fires associated with each fire scenario group (ie. for each area of a building) have been determined using the statistics presented in earlier sections and the information given in Section 8.4.2. The results for all combinations of factors are summarised in Table 8.5. As noted previously, the effect of all factors considered in the previous section cannot be quantified. These factors have been omitted in the analysis.

8.4.4 DISCUSSION

It is preferable to reduce the occurrence of all fires but this can only be achieved through better monitoring, housekeeping, and maintenance (see i and ii in Section 8.4.2). If this is applied to electrical equipment it appears that fire starts could be reduced by up to 14%. Obviously, further reductions could be achieved through good housekeeping in relation to the use of appliances and heaters, but this has not been able to be quantified.

The containment of fires to C1 fires is really important as these fires will have little impact on the occupants or on property. The greater the level of surveillance and staff fire fighting training, the more likely will fires be contained while they are small. It is possible, with modern shopping centres, that this factor is greater than suggested by the USA statistics presented in this section. However this cannot be quantified.

The presence of non-combustible construction in structural areas will have a greater influence in limiting fires to the area of fire origin. What materials constitute *non-combustible* construction is currently under review in Fire Code Reform Centre Project 2 and reference is made to that project for clarification of this matter for the use of materials in sprinklered shopping centre buildings.

It is very important to reduce the number of C3 fires as these pose the greatest threat to human life. It can be observed from Table 8.5, that although all of the factors presented in Section 8.4.2 have an influence, a soundly managed sprinkler system (compared with that associated with the base case) has the greatest impact in reducing the likelihood of these fires—reducing them by a factor of between 20 and 30. However, it cannot be assumed that the improvement in life safety will be of the same order. The reason for this is that although there is a strong correlation between the number of deaths and the extent of flame spread, deaths have occurred in sprinklered buildings where the sprinklers have operated and contained the fire to the area of fire origin.

One observation that can be made with respect to Table 8.5 is that the likelihood of having a C3 fire, with a soundly managed sprinkler system, is *extremely* small. It is therefore considered appropriate that the primary design fire for these buildings, for the purpose of designing smoke management and the building structure, should be a sprinklered fire. The impact of a C3 fire does however need to be considered. This is considered further in Chapters 11 and 12.

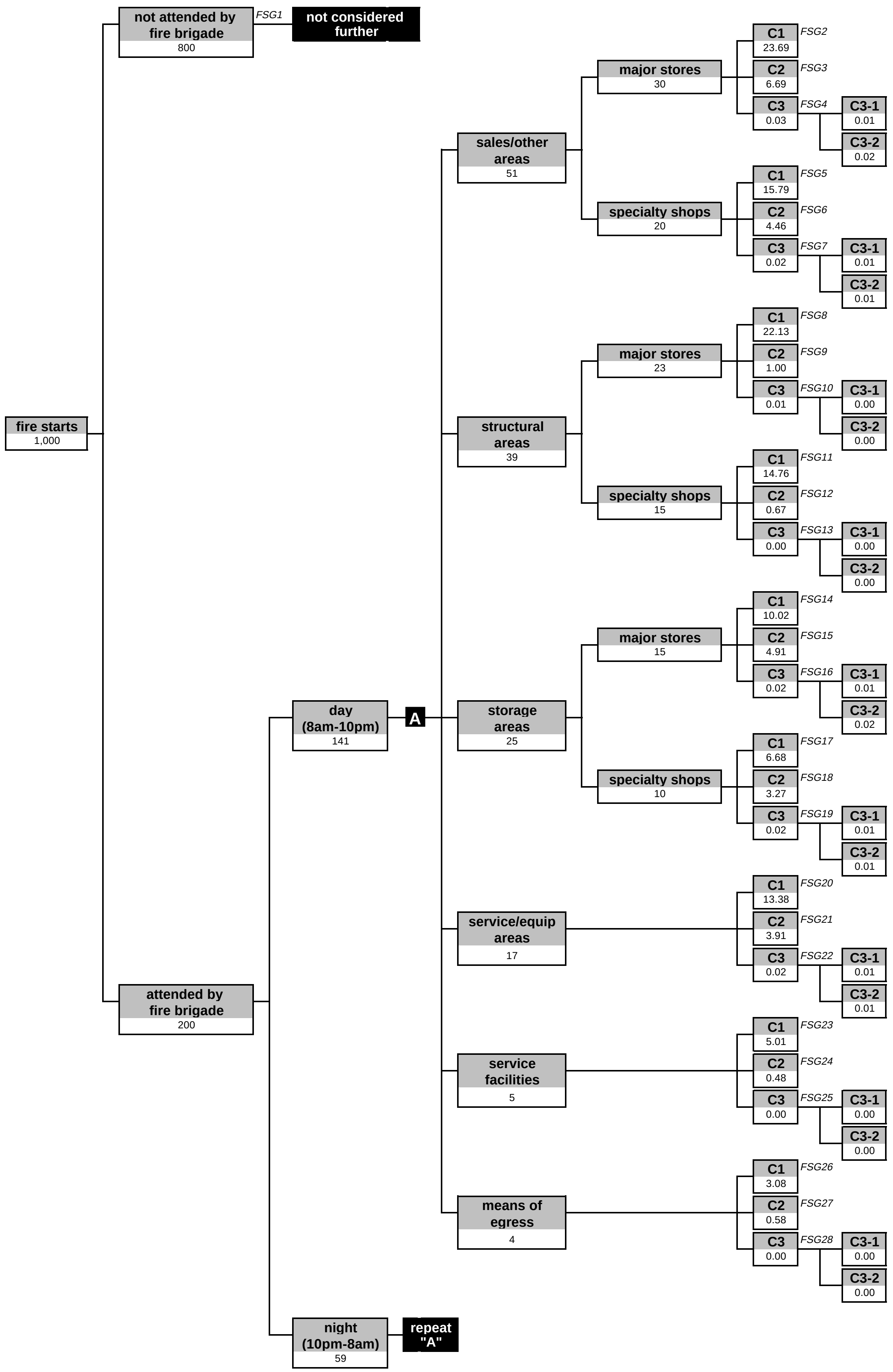


FIGURE 8.2 NUMBER OF FIRES ASSOCIATED WITH FIRE SCENARIOS WHEN NON-COMBUSTIBLE CONSTRUCTION IS USED AND SPRINKLER SYSTEM IS SOUNDLY MANAGED

TABLE 8.5 NUMBER OF FIRES ASSOCIATED WITH THE FIRE SCENARIO GROUPS

factors			*factors included*						
• *monitoring electrical switchboards*			✗	✗	✓	✓	✗	✓	✓
• *residual current protection*			✗	✗	✗	✓	✗	✗	✓
• *non-combustible construction*			✗	✓	✓	✓	✓	✓	✓
• *soundly managed sprinkler system*			✗	✓	✓	✓	✗	✗	✗
• *improved & soundly managed sprinkler system*			✗	✗	✗	✗	✓	✓	✓
area	*FSG*	*fire*	*number of fires*						
sales/other	*2*	*C1*	23.69	23.69	21.55	20.20	23.69	21.55	20.20
	3	*C2*	5.78	6.69	6.08	5.70	6.69	6.08	5.70
	4	*C3-1*	0.32	0.01	0.01	0.01	0.01	0.01	0.01
		C3-2	0.62	0.02	0.02	0.02	0.02	0.02	0.02
	5	*C1*	15.79	15.79	14.37	13.46	15.79	14.37	13.46
	6	*C2*	3.85	4.41	4.02	3.76	4.46	4.06	3.80
	7	*C3-1*	0.21	0.02	0.02	0.02	0.01	0.01	0.01
		C3-2	0.41	0.04	0.04	0.04	0.01	0.01	0.01
structural	*8*	*C1*	19.12	22.13	20.14	18.87	22.13	20.14	18.87
	9	*C2*	3.46	1.00	0.91	0.86	1.00	0.91	0.86
	10	*C3-1*	0.10	0.00	0.00	0.00	0.00	0.00	0.00
		C3-2	0.46	0.00	0.00	0.00	0.00	0.00	0.00
	11	*C1*	12.74	14.76	13.43	12.58	14.76	13.43	12.58
	12	*C2*	2.31	0.66	0.60	0.56	0.67	0.61	0.57
	13	*C3-1*	0.07	0.00	0.00	0.00	0.00	0.00	0.00
		C3-2	0.31	0.01	0.01	0.01	0.00	0.00	0.00
storage	*14*	*C1*	10.02	10.02	9.11	8.54	10.02	9.11	8.54
	15	*C2*	4.24	4.91	4.47	4.19	4.91	4.47	4.19
	16	*C3-1*	0.23	0.01	0.01	0.01	0.01	0.01	0.01
		C3-2	0.46	0.02	0.02	0.01	0.02	0.02	0.01
	17	*C1*	6.68	6.68	6.08	5.69	6.68	6.08	5.69
	18	*C2*	2.83	3.24	2.95	2.76	3.27	2.98	2.79
	19	*C3-1*	0.15	0.02	0.01	0.01	0.01	0.00	0.00
		C3-2	0.31	0.03	0.03	0.03	0.01	0.01	0.01
service/ equipment	*20*	*C1*	13.38	13.38	12.18	11.41	13.38	12.18	11.41
	21	*C2*	3.38	3.89	3.54	3.32	3.91	3.56	3.33
	22	*C3-1*	0.21	0.02	0.01	0.01	0.01	0.01	0.01
		C3-2	0.34	0.02	0.02	0.02	0.01	0.01	0.01
service facilities	*23*	*C1*	5.01	5.01	4.56	4.27	5.01	4.56	4.27
	24	*C2*	0.42	0.48	0.44	0.41	0.48	0.44	0.41
	25	*C3-1*	0.02	0.00	0.00	0.00	0.00	0.00	0.00
		C3-2	0.04	0.00	0.00	0.00	0.00	0.00	0.00
means of egress	*26*	*C1*	3.08	3.08	2.80	2.62	3.08	2.80	2.62
	27	*C2*	0.50	0.57	0.52	0.49	0.58	0.53	0.49
	28	*C3-1*	0.01	0.00	0.00	0.00	0.00	0.00	0.00
		C3-2	0.07	0.01	0.01	0.01	0.00	0.00	0.00

9. BUILDING LAYOUTS

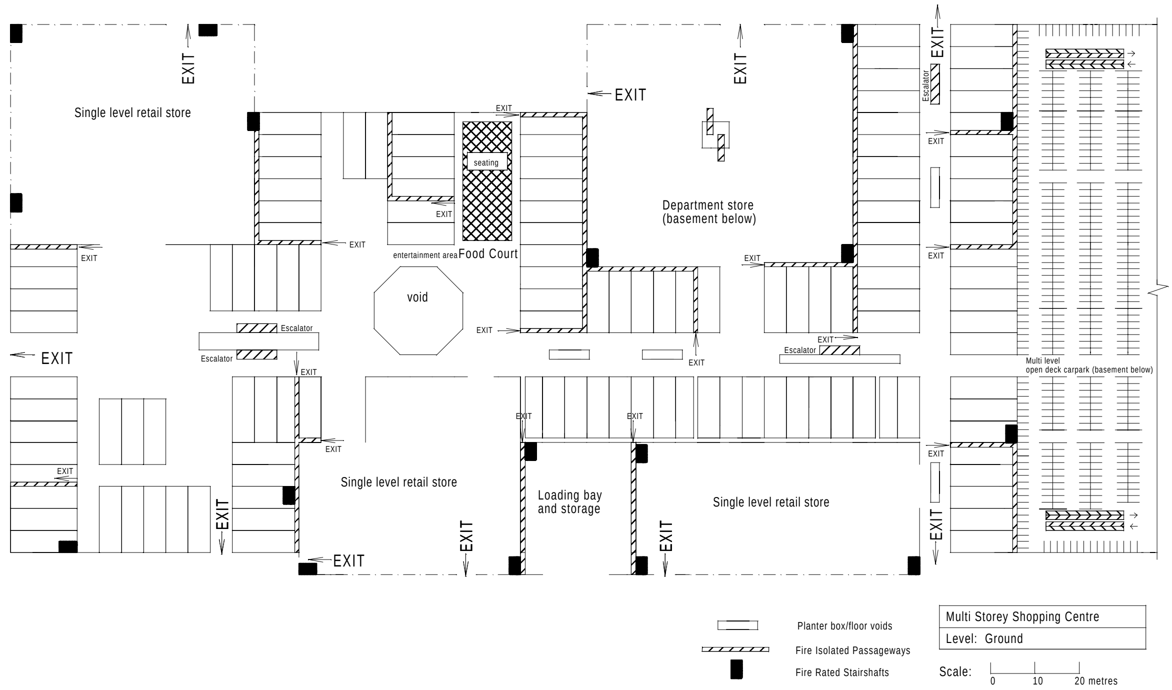
The role and importance of the various fire-safety systems and the impact of the possible range of fire scenarios (see Chapter 8) on a building needs to be understood in relation to building layouts which embody sufficient features to make them illustrative of the buildings which form the subject of this report. Layouts of such a building are shown in Figure 9.1. The building has a rise in storey of four and a total gross lettable floor area of about 75,000 m^2.

This building is "constructed" based on the findings of the shopping centre survey described in Chapter 6. It contains:

- A *mall* which runs throughout the building at all levels. It opens on to the street at ground level. The levels are 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 also has a vaulted roof.
- A multitude of *specialty shops* at each level which open directly into the mall at the front.
- A multi-storey *department store* on each level. The levels are interconnected by escalators/travelators located at the centre of the store. The store fronts into the mall at each level with a wide entrance. Variations to this store are considered later in Chapter 11, particularly in relation to the whether the front of the store opens into the mall on all levels or just the lower levels. The latter arrangement is typical of shopping centres where a four-storey department store is built adjacent to a two or three storey mall.
- A number of single-storey *major stores* at each level. Each of these stores opens into the mall with a wide entrance.
- A *food court* at ground level with open food outlets and an open seating area.
- A *cinema complex* at level four. The complex contains 7 theatres. Each theatre opens directly into the mall. There are also exits behind each theatre in accordance with the BCA requirements.
- A multi-storey *carpark* which opens into the mall at various levels..

The layouts also show service tunnels and fire isolated passages as required by the BCA. Exits within the building are provided so as to satisfy the minimum requirements of the BCA. The relative proportions of the mall, specialty shops and major stores are similar to those associated with major shopping centres throughout Australia.

The building chosen above has been adopted to assist discussion on various fire safety issues in later chapters and for the purpose of analysis of various smoke management options. Major stores can be significantly larger than those associated with this building and the mall geometry can also vary. The effect of such geometric variations on occupant evacuation and smoke management are considered in Chapters 10 and 11.



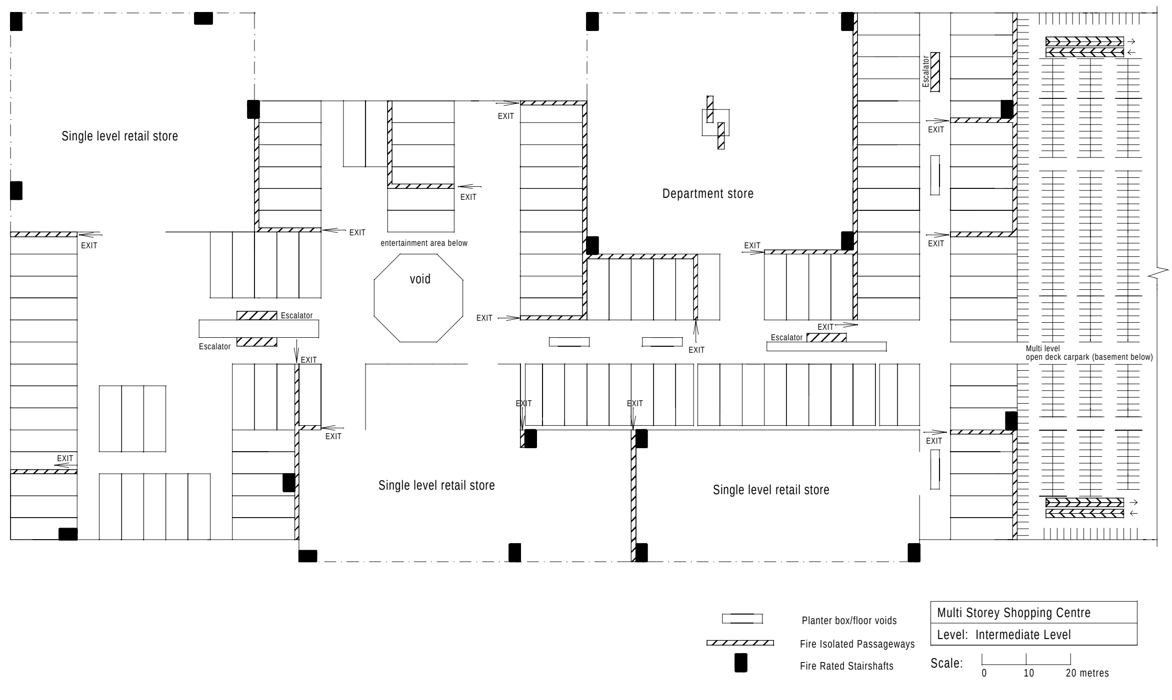
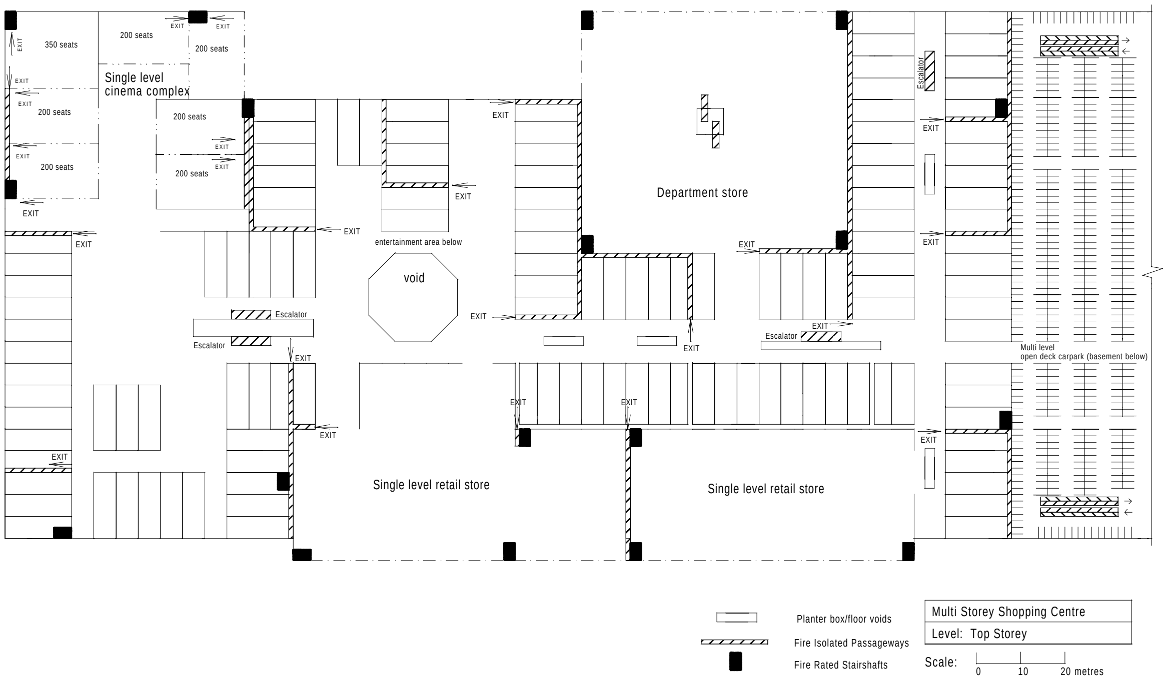
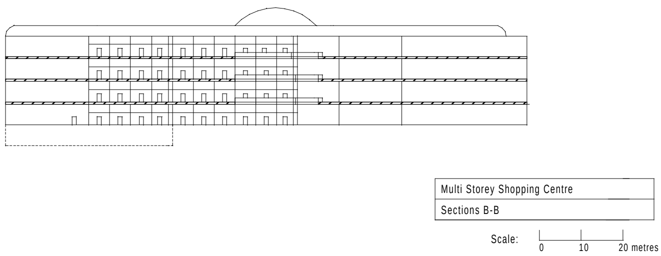


FIGURE 9.1 BUILDING LAYOUT





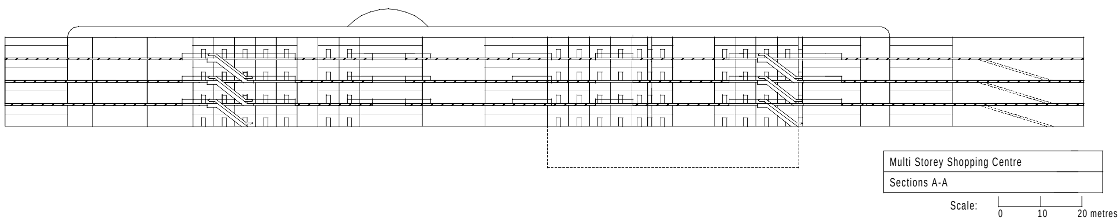


FIGURE 9.1 BUILDING LAYOUT (CONT'D)

10. OCCUPANT RESPONSE AND MOVEMENT

10.1 INTRODUCTION

Shopping centre occupants include both shoppers and staff. Staff can be further divided into shopkeepers, store management and centre management (including security and cleaners).

☛ *The presence of an Evacuation Management Plan and associated training is of fundamental importance.*

This is taken extremely seriously in most major centres with well documented roles and responsibilities and ongoing training. In the remainder of this chapter, it will be assumed that such a plan is in place and that wardens have been appointed. Wardens are generally appointed by centre management and their function is to assist with evacuation in the event of an emergency. This is an important function. The "house warden" is normally associated with centre management and is the person who assumes responsibility in the event of an emergency.

The purpose of this chapter of the chapter is to better understand the role of occupants with respect to detection and fire fighting, and the factors and times associated with the *initiation* of evacuation. The occupant's choice of direction and the time required for movement to a safe place are important matters and are considered further in this chapter.

10.2 DETECTION AND FIRE FIGHTING

10.2.1 INTRODUCTION

The occupants of the building can have an important role to play with respect to both fire detection and fire fighting. That role is now considered.

10.2.2 DETECTION

As noted in Chapter 8, a high proportion of fires (F_{SG1}) that start in buildings are self extinguished or extinguished by the occupants, without the brigade being notified. However, if the fires that result in call-outs to the fire brigade are considered, then the following statistics apply for unsprinklered buildings in the USA:

TABLE 10.1 EXTENT OF FLAME DAMAGE AS FUNCTION OF TIME OF DAY

Location of Fire Start	*% of fires beyond the area of fire origin*	
	day †	*night*
sales/other	22.1	47.9
service facilities	8.8	25.7
service/equipment areas	22.7	45.7
structural areas	17.4	38.0
means of egress	15.9	37.4
storage areas	33.0	55.7

† day is taken as the between 8 am and 10 pm

No data are available on the use of hose reels within the building as the fire incident form completed by the fire fighter has no provision for this. Such hose reels are provided for occupant use. According to the above data, a much greater percentage of fires are self extinguished or extinguished by make-shift means or fire extinguishers during the day than at night. This is not surprising given the data presented in Section 10.2.2. At first, it is difficult to see why there should be a difference in the percentages of self-extinguished fires between night and day. The explanation appears to be that in many of these fires there is some human interaction (eg. moving the object or turning off power) but that the fires were taken by the fire brigade to be largely self extinguished.

Table 10.2 shows that a higher percentage of fires are extinguished by extinguishers in NSW compared with the USA. This may be due to the greater availability of extinguishers in Australian buildings

Thus it appears that the occupants of a building have an important role to play in fire-fighting, or in controlling the fire until the brigade arrives.

☛ *It follows from these data that the provision of extinguishers with associated training can have a major impact on fire safety in these buildings.*

In many larger centres and most larger stores, staff are trained in the use of fire extinguishers and what to do in an emergency.

One issue that was raised during the survey of shopping centres [5] is the problem associated with the security of extinguishers in mall areas where they are commonly located. This matter has been resolved in some centres by locking the fire cabinets which contain the extinguishers and incorporating a break-glass access key. Other centres have required specialty shops, concessions, and stores[21] to provide and maintain their own extinguishers as part of the lease agreement, and therefore have affectively relocated extinguishers closer to where they are likely to be required and into a relatively secure environment.

☛ *It is our opinion, that greater security of extinguishers can be achieved if extinguishers are provided in specialty shops, concessions, and stores, rather than in the mall walkway.*

10.3 EVACUATION BEHAVIOUR

10.3.1 INTRODUCTION

The time for evacuation of the occupants from a particular part of a shopping centre building may be taken as:

$$t_e = t_{pm} + t_m \tag{10.1}$$

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 movement time for the occupants to move to a safe place. This movement time is a function of the choice of exit and the speed of travel and the number of people queuing at the exits.

[21] Major stores provide their own equipment.

10.3.2 KEY FACTORS

As noted earlier in this report, Emergency Warning and Intercommunication Systems (EWIS) are not strictly required in these buildings unless they have an overall height of more than 25m or are classed as an atrium. In the case of cinemas, an EWIS must be provided. Therefore, many shopping centres will not be required to have an EWIS, but, most have some form of PA system. These systems, in addition to other functions, provide audible “alert” and “evacuation” signals in the relevant part of the building upon receipt of an alarm at the Fire Indicator Panel (FIP). The alarm at the FIP panel is also automatically transmitted to the fire station.

☛ *The training of staff to act as wardens to assist with building evacuation is important as is the development of a sound evacuation strategy.* Adequate means of communication between wardens is important during an evacuation and this will be best achieved by portable radios rather than the WIP phones located near exits—these being more applicable to high-rise buildings—than to shopping centres.

A review of emergency incidents in shopping centres and a series of interviews with shopping centre staff and management has been undertaken as part of this research program (Appendix 10.1) On the basis of this work the following observations are made:

i. The presence of an “alert” signal makes shoppers aware that “something” could be happening but is unlikely to achieve the intended effect—ie. preparation to evacuate. Should the signal go to “evacuation”, it is *unlikely* that evacuation will be initiated.

ii. 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. However people may not move away from thin smoke.

iii. The decision to evacuate or move away from the fire-affected area will be positively reinforced by the presence of wardens and staff. Indeed, retail buildings are supervised environments where shoppers expect guidance and direction. The occupants will respond to instructions from a member of staff—especially if that staff member has some mark of authority as is normally the case.

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.

iv. It is important to understand on what basis shopping centre staff will make the decision to commence evacuation. This question is considered in relation to each area in a shopping centre.

Specialty Shop of Fire Origin—In this case, the presence of dense smoke[22] in the shop will be sufficient for the shop keeper to commence evacuation—assuming that the occupants have not

[22] Observation of the behaviour of uninitiated observers during the fire tests described in Section 5 revealed the tendency of these people to overestimate the potential danger of a fire. There will be the same tendency with shopping centre staff and wardens. Thus they are likely to initiate evacuation at the first sight of dense smoke in that part of the building.

already made their way out of the shop. The responsibility of the shop keeper for evacuation of the shop ends when the occupants are in the mall.

Major Store/Department Store of Fire Origin—In this case, the decision to evacuate is made by store management and staff are generally trained to facilitate this (see Appendix 10.2). *Such training is important*. The decision to evacuate will be made on the basis of the presence of dense smoke or upon the advice of the fire brigade.

Mall Areas and Neighbouring Stores—The release of dense smoke into the mall poses a threat to property in adjacent stores. For this reason, operators of adjacent specialty shops may wish to evacuate their stores so that the front doors can be closed to minimise smoke damage. However, the decision to evacuate adjacent stores and the mall areas lies with centre management. However, in this case, they will generally wait for advice from the fire brigade unless there is dense smoke entering the mall. This is due to the commercial implications of unnecessarily evacuating a centre or part of a centre.

If the fire is sufficiently large that other levels of the mall begin to experience dense smoke, then evacuation of these smoke-effected parts will be initiated.

v. 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. This fear of emergency exits is particularly so when the doorway leads into a passage. This is usually the case with an emergency exit from a mall under the current regulatory requirements.

10.3.3 PRE-MOVEMENT TIME

In considering pre-movement time, it is important to review previous fire incidents where deaths have occurred and to understand the implications from the statistical data.

There are relatively few deaths in retail buildings. The available fire statistics and major fire incidents appear to show that deaths have mainly occurred in retail buildings when:

i. persons were asleep or incapacitated by drugs or alcohol at the time of the fire (most common situation[23]) and did not move. The pre-movement time for these people is irrelevant.

ii. persons were intimately involved with starting the fire[24]. Again, it can be argued that the pre-movement time is irrelevant.

---

[23] Of the 86 fatalities recorded for 77,996 fires in the USA, 36 appear to have been asleep at the time of the fire. Many of these fires would appear to be associated with residential parts of retail buildings.

[24] Of the 86 fatalities recorded for 77,996 fires in the USA, between 7 and 14 appear to be people who were intimately associated with starting the fire.

iii. persons were too young or old to act by themselves[25]. It is unlikely that such deaths can be prevented unless the building is a "supervised" environment. As observed in the previous section, this is generally the case with modern shopping centres but it is important to emphasise the importance of the roles and responsibilities of shopping centre management in providing adequate support and supervision in any building evacuation.

iv persons were in a room away from the area of fire origin, but where the exit or exits from the room were cut-off by smoke before the occupants became aware of the fire[26]. As the occupants are not aware of the fire it is not meaningful to associate a pre-movement time with this situation. This situation is shown schematically in Figure 10.1(a) and emphasises the importance of providing alternative exits and ensuring that at least one of these cannot be smoke logged at the same time, and of adequate warning devices. Cinemas are an example of parts of buildings that must fulfil these criteria. Some specialty shops may also present a problem if there is only one exit/entrance.

☛ *Avoiding entrapment is of fundamental importance.*

v persons in the area of fire origin delayed evacuation until it was too late and the room became smoke logged[27].

The situation described in v. is now considered in more detail in relation to the matter of pre-movement time and is illustrated in Figure 10.1(b). If this situation was a common occurrence we would expect to see a much higher death rate in retail buildings and many multiple fatalities. This is not the case and mostly there have been single and double fatalities. It appears therefore that people in these buildings can, in the main, "outrun" the fire—at least with the exit spacing and widths associated with current regulations[28]. What does this imply about pre-movement times?

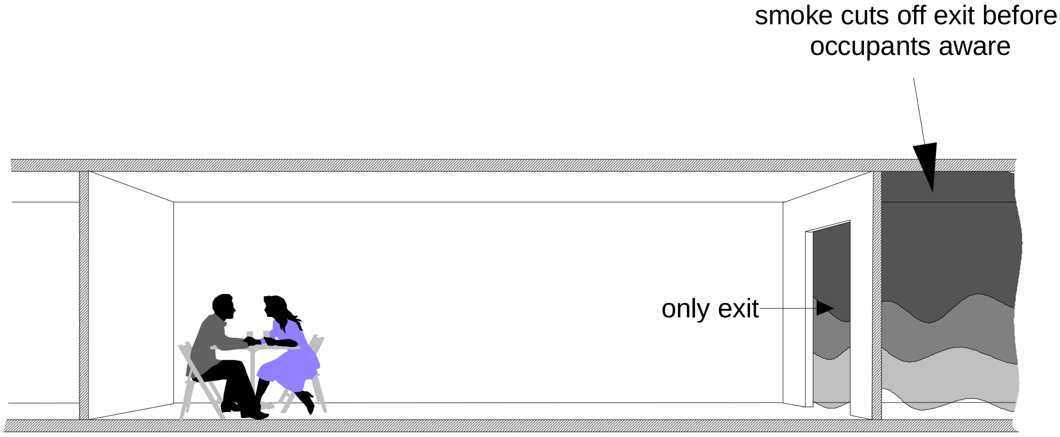
---

[25] Of the 86 fatalities recorded for 77,996 fires in the USA, 12 were people who were bedridden or too young or old to act. The deaths associated with the young were when the associated adults also died or were badly injured. Flammable liquids were also involved in many of these cases. The fact that people were bedridden again suggests residential parts of the building.

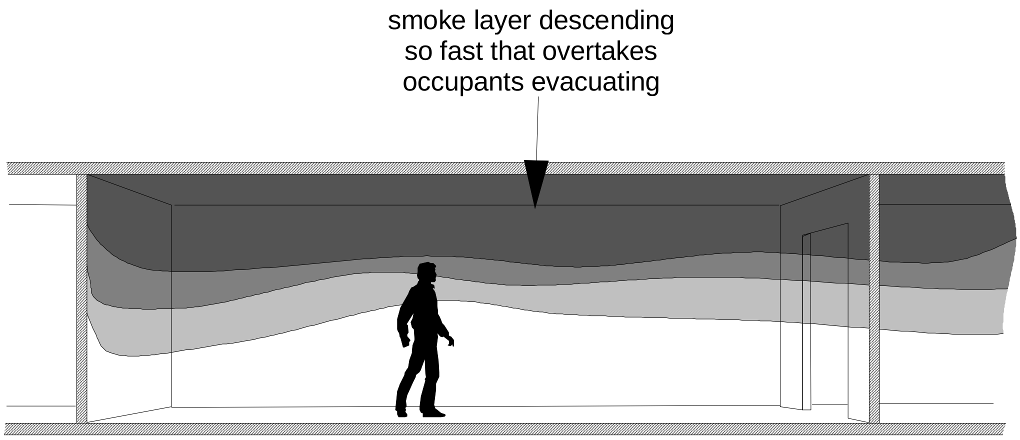
[26] Examples of this include the recent fire in Dusseldorf Airport terminal where people were trapped in an airline lounge - only one exit which was smoke logged. Also the fire in the L'Innovation building in Brussels in the 1967 where 200 people in an upstairs restaurant were trapped when the exits from this room became smoke logged. The remainder of the building was largely empty at the time of the fire and there was no warning system.

[27] An example of this is the fire in Woolworths in Manchester in 1979 where 10 elderly people died within a restaurant adjacent to the fire area when that part of the building became smoke logged. The victims continued with their meals despite being told to evacuate. Other people on the floor evacuated successfully. The building was not sprinklered and was deficient in many other aspects.

[28] Exit requirements are similar in the USA and Australia.



(a) exit cuts off by smoke



(b) smoke layer decending rapidly

FIGURE 10.1 SITUATIONS WHERE OCCUPANTS MAY BE TRAPPED

Considering the range of layouts that can be associated with unsprinklered buildings in the USA, it is found (Appendix 10.3) that the time to untenable conditions, in the event of a fast growing fire, is similar to that experienced with Test 2 (see Chapter 6) and within one or two minutes of the evacuation time calculated on the basis of accepted values for travel speed. This suggests that the pre-movement time is likely to be very short—of the order of a minute or so from the first sight of dense smoke. Of course, pre-movement time will be variable and dependent on the fire. If the fire is not threatening (no dense smoke) then the pre-movement time may be very large—but in these situations, the fire is relatively non-threatening and there is much time available for evacuation, should this even be considered necessary.

10.3.4 OCCUPANT MOVEMENT

10.3.4.1 Introduction

Once the decision to evacuate has been made, the efficient movement of people to a safe place must be achieved. This will depend on many factors including the type of exit, the distance of travel, the exit widths, the number of people in that part of the building, the speed of travel and the amount of queuing that occurs . These matters are now considered.

10.3.4.2 Numbers of People

The BCA gives specific guidance on number of people per m^2 of floor area that may be assumed for design purposes. The recommended numbers are 1 person per $3m^2$ for shops where major access is available from ground floor, and 1 person per 5 m^2 for mall areas and upper levels of stores where major entrances from outside are not available. These numbers are not only relevant to the matter of fire safety but also to practical issues such as the provision of appropriate sanitary facilities.

MacLennan [20] gives a good summary of the overseas code requirements for numbers of people in retail buildings. Also presented are the results of various surveys of shop populations—usually conducted around Christmas time when the number of people in the building is a maximum.

The population in a building varies not only during the day but throughout the week and from week to week throughout the year. It also varies from year to year. It is more or less constant over a year with the exception of Christmas and other relatively infrequent occasions (stocktaking sales) when populations almost double [5]. These extreme values of population have not been used for the evacuation calculations undertaken as part of the life safety evaluation presented in Chapter 11. The reason for this is that the simultaneous occurrence of maximum population, a fire failing to be noticed and extinguished, sprinkler isolation in the area of fire origin, and a "worst-case" unsprinklered fire is considered to be very unlikely. Rather, a lesser but still conservative value is used. This alternative value was determined from measured data presented in [5] and its derivation is given in Appendix 10.4. A comparison of these values with the BCA values is given in Table 10.3.

TABLE 10.3 AREA PER PERSON

Location within Centre	*Area per Person (m^2)*	
	Alternative	*BCA*
mall and upper levels with restricted access	10	5
shops	6	3

10.3.4.3 Observations on Exit Spacing and Travel Distances

The BCA specifies the minimum and maximum spacing between exits, and the aggregated exit widths required for storeys of a building. The basis of these provisions is known to be somewhat arbitrary. From an economic viewpoint, exit spacing requirements can interfere with building flexibility and layout, whilst each metre of required exit width utilises otherwise lettable floor area and often is connected to a stair. It must be remembered that the positions of stairs for the purpose of facilitating egress from an upper floor will impact on the floors below as the stairways must go down to ground level. That is, the exits required at an upper level may not be required at the lowest level; but the fact the upper exits must reach ground level means that stairs must be provided through all levels.

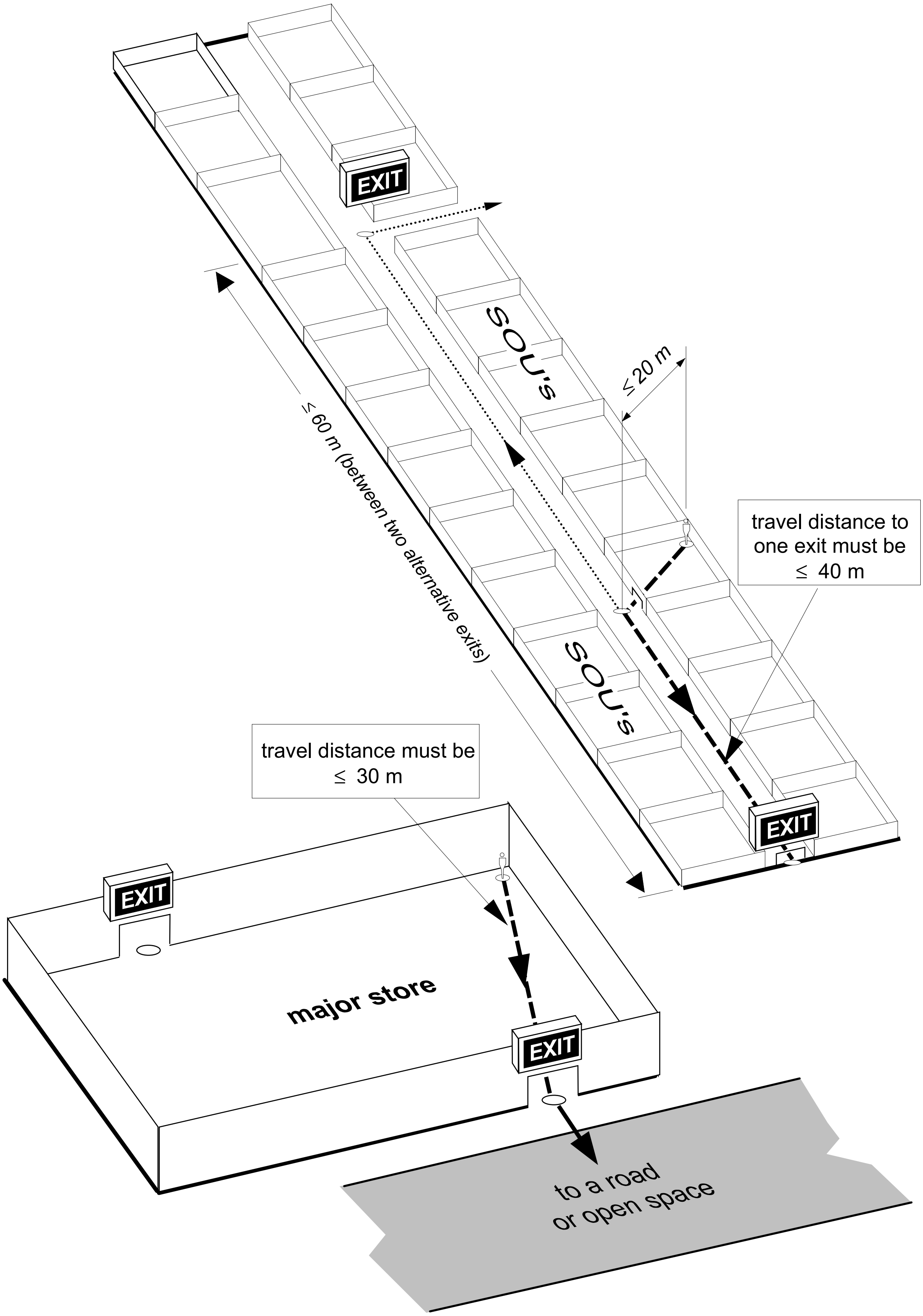
The BCA exit spacing requirements are summarised in [4], and are again illustrated in Figure 10.2 in relation to a department store and a mall. It is interesting to consider the situation that arises concerning entrances to a store. If the entrance faces into a street then it can be counted as a required exit[29]. This is the case because the street is considered to be "open space"—or alternatively, a "safe" place. If, on the other hand, the entrance opens directly into a mall (Figure 10.3) the entrance *cannot* be treated as a required exit but only as part of the pathway to a required exit. *This matter begs the question: under what conditions can a shopping mall or other parts of a building be regarded as a safe place?* The presence of "furniture" in a major store means that it is not possible to evacuate "as the crow flies" but that people must move along essentially orthogonal paths, depending on their location. Assuming that the store is approximately square, this could increase the travel time of the person furthest from an exit by up to 40%. The overall impact of this factor on evacuation time is generally small as the major component of time is usually associated with queuing at the exits.

The above question is addressed in Chapter 11.

10.3.4.4 Movement Hierarchy

Once people have decided to evacuate, in which direction will they go or be directed? Based on the evacuation behaviour described in Section 10.3, the following movement hierarchies are proposed.

[29] A required exit is one which is required by the BCA for the purpose of providing adequate egress from the building.



not to scale

FIGURE 10.2 EXIT TRAVEL DISTANCE

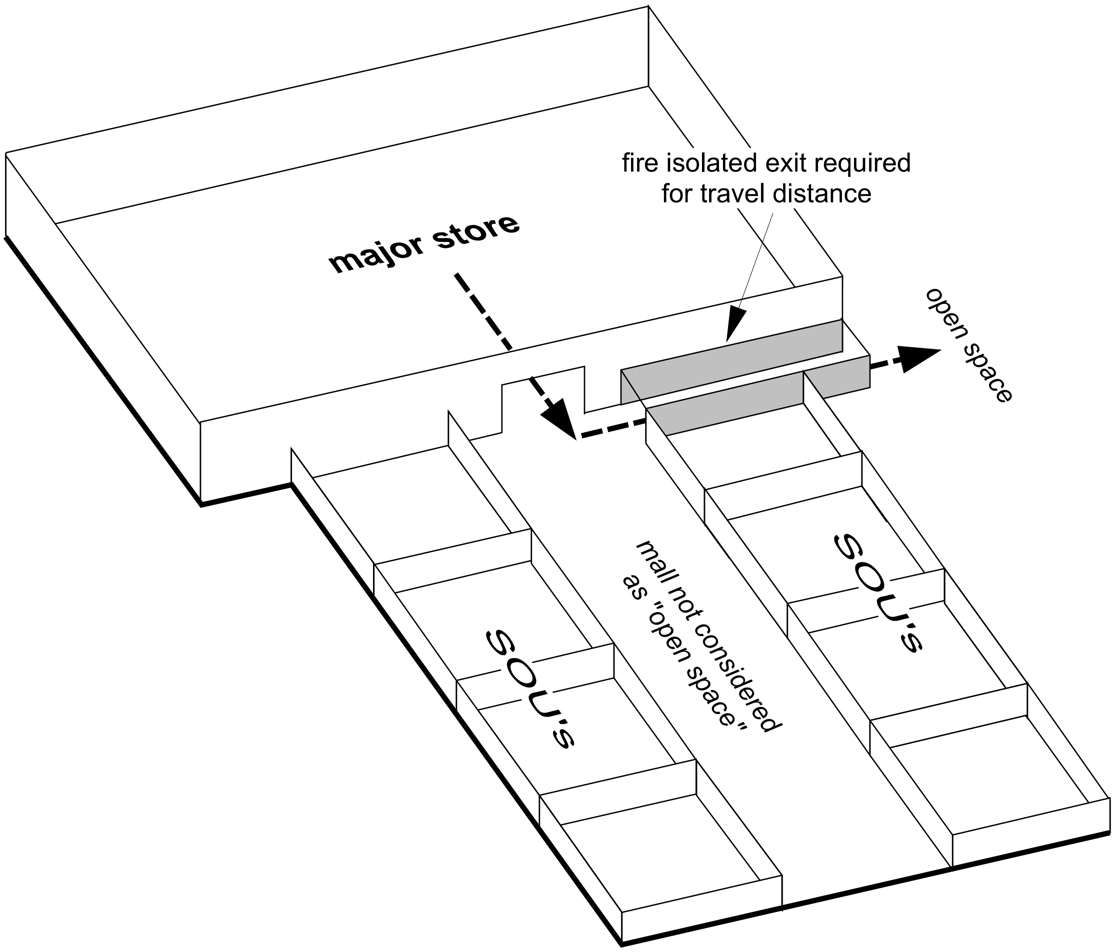


FIGURE 10.3 EXIT TRAVEL DISTANCE

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—Occupants will move into mall when dense smoke becomes evident in this part of the mall. Once in the mall, people will move away from the fire area.

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 there is a perceived threat from smoke within the mall. If that is the case, movement will be towards the familiar entrances unless the dense smoke layer reaches to the entrance to the store. In that case, movement will be towards the emergency exits. This is due to the fact that dense smoke near (but above) the main entrance will be perceived as a greater threat than using the emergency exits.

In the case of shops or stores on the level directly above the store of fire origin, the same movement criteria apply[30].

The 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 be sought by the occupants and staff 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 and escalators.

[30] In this case however, movement will be initiated earlier as smoke will be much more in evidence than for parts of the building further away.

10.3.4.5 Modelling of Movement

Simple calculations of movement time are satisfactory when considering the evacuation out of a store. However, when considering evacuation through a number of exits out of a shopping centre building, the movement times may be affected by factors such as queuing, mixing of flows and warden control. For this, it is more desirable to use a computer model. EvacSim [21] is a model which can take these effects into account and has been used in the evacuation analysis of mall case study reported in Section 11.6.3. Both these forms of evaluating evacuation or movement times are described below.

(a) *Simplified Calculation*

The simplified method is used for the calculation of movement times out of a shop. The movement time for occupants in specialty shops is relatively short because of the relatively small area of specialty shops. Because the occupants of internal specialty shops discharge directly into the mall, the evacuation of these occupants is more appropriately considered in the evacuation of malls.

The simplified calculation method is therefore more applicable for the evacuation analysis of major stores where the population is greater. In addition, it may be assumed that the shoppers in a large store are sufficiently dispersed throughout the store such that the travel time of the nearest occupant to an exit is relatively short. An allowance for a travel time equal to the time it takes occupants to travel one half of the maximum travel distance to an exit is therefore ample. Hence the simplified method of calculating movement time t_m comprises the average travel time to an exit t_{mt} and the time for occupants to pass through the exits t_{mq}, ie.,

$$t_m = t_{mt} + t_{mq} \tag{10.2}$$

Adopting a horizontal time speed of 1.2 m/s [48], the travel time is therefore

$$t_{mt} = d_t/1.2 \tag{10.3}$$

where d_t is the average travel distance. d_t may be taken as the half the maximum separation distance between two exits.

The time t_{mq} (s) for a queue of n persons to discharge from exits with a total effective width W_e (m) is given as follows [47]:

$$t_{mq} = n/(F_{sm}\times W_e) \tag{10.4}$$

where F_{sm} is the maximum specific flow. The value of F_{sm} is about 1.0 for stairs and 1.3 for horizontal travel. The total effective width is the sum of the clear widths of all exits less 0.3 m for each exit.

It should be noted that these values of flow and travel speed are low estimates rather than high. They will therefore generally lead to conservative (ie. high) movement times.

When considering the movement time beyond the shop or where occupants need to pass through a number of exit points, the calculations can be overly complex and the use of a computer model such as EvacSim is more appropriate.

(b) *EvacSim*

The movement parameters for EvacSim is described in more detail in [21]. In addition to being able to allow for queuing, mixing of flows and warden control of evacuation sequence, there are movement and behavioural modes adopted in the model. For example, if an enclosure has a number of exits, the choice of an exit by an occupant may be modelled to allow for the following factors:

a) the distance between the occupant and the exit,

b) the length of the queue at the exit, if any,

c) the familiarity of the occupant with the exit,

d) whether the exit is blocked by the effects of fire,

e) the mode of the occupant, ie. whether the occupant is evacuating the building or going to another part of the building.

11. SMOKE MANAGEMENT

11.1 INTRODUCTION

It is known that a primary cause of death in fire is exposure to the products of combustion—smoke. 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. High temperatures in a hot smoke layer also presents a threat to the occupants.

In the event of a fire, because it is hotter than air, smoke will rise and move through a 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. This means that both smoke control and evacuation of the occupants are key components of the smoke management system. 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—small fires generate small quantities of smoke.
- providing adequate exit paths and evacuation strategies—to quickly move people away from the smoke affected areas.
- providing sufficient smoke reservoirs—allow the smoke to accumulate above the occupants so as not to envelop them too quickly (or even at all).
- providing adequate venting/extraction where appropriate—removing smoke from the building and away from the 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 density and content of the smoke and the length of exposure to it.

Modern shopping centres contain large open spaces and this is beneficial from a life safety viewpoint as it means that the occupants can move away from a fire and that the building has a significant capacity to absorb smoke. This is particularly the case with the malls associated with most larger centres. Access to the various levels of these buildings is provided at a number of points—from adjacent carpark levels or streets, or from another level within the mall by means of escalators or open stairs. In the event of a fire emergency, the usual means of access and egress are the means of egress that will be used by the occupants—rather than emergency exits connected to tunnels leading to other parts of the building or to outside.

☞ *Thus, modern shopping centres exhibit characteristics that are beneficial and that should be used in developing a rational approach to life safety and smoke management in sprinklered shopping centre buildings.*

The purpose of this chapter is to develop specific guidelines for a rational approach to smoke management in these buildings. These guidelines have been developed on the basis of the fundamental principle:

☛ *Entrapment of occupants should be avoided through the provision of sufficient exits (type, number and location) to allow escape from any* ***credible*** *threat.*

11.2 SMOKE ASSOCIATED WITH FIRE SCENARIOS

11.2.1 INTRODUCTION

Before considering the need for smoke exhaust or venting, it is necessary to consider the quantities and type of smoke generated by each of the fire scenario groups described in Chapter 8. The potential impact of each of the fire scenario groups on life safety is then considered as is the corresponding likelihood of occurrence.

Some interesting facts about smoke were demonstrated by the test program described in Chapter 6.

> *Sprinklered Fires*— For the situations where sprinkler activation resulted in application of the water to the seat of the fire, clouds of white smoke were generated. The smoke was white because it contained substantial steam and was sometimes buoyant and sometimes remained at ground level. Even at ground level, and without the benefit of extraction or venting, this smoke did not pose any threat to life in the burn hall because it was sufficiently dilute—as evidenced by the fact that persons within the burn hall were able to walk through the smoke with little or no discomfort.
>
> In the case of sprinklered fires where activation of the heads did not result in direct application of water to the seat of the fire due to shielding from racking and shelving, significant volumes of dense black smoke were generated. The volume of smoke was enhanced by air entrainment associated with the action of the sprinklers and the generation of steam. The entrainment of air and the water vapour however also resulted in substantial cooling of the smoke and in it having a lower optical density than smoke associated with an unsprinklered fire. Despite the cooling effect from the sprinklers, the smoke was found to be sufficiently buoyant to rise to the roof of the burn hall and not remain at ground level.
>
> *Unsprinklered Fires*—These fires were characterised by very large quantities of dense black smoke, with the smoke being very buoyant, with temperatures of more than 300°C at the roof of the burn hall. The smoke layer descended very rapidly due to the rate of combustion and consequent rate of smoke generation. These fires represent, by far, the greatest threat to life. Fortunately, they will be very rare in a sprinklered building.

As a general observation, it can be stated that optically more dense and more toxic smoke tends to be hotter and therefore more *buoyant* than optically less dense (thin) smoke—but that thin smoke will not present a threat to the occupants.

It is important to gain an understanding of the average probability of occurrence of the various types of fire. Given *1000* fire starts in a typical shopping centre building with a soundly managed sprinkler system (see Chapter 8)—this corresponds to 50 years of service life in a building with a GLAR of 75,000 m^2 (see Chapter 9)—800 of these fires will be F_{SG1} fires, with 200 attended by the fire brigade: of these latter fires, 141 will occur during occupied hours with 114.5 C1 fires, 26 C2 (sprinklered) fires ($\frac{26}{1000} \times 100 = 2.6\%$), and less than 1 C3 fire (potentially larger fires when sprinklers fail to operate).

It seems inappropriate therefore for the primary design fire (for considering life safety) to be other than a sprinklered fire.

☛ *In considering the impact of smoke on the occupants, the* primary *design fire for these buildings should be a* sprinklered *fire (ie. a C2 fire).*

This is particularly so where the building has a soundly managed sprinkler system resulting in very low probability of occurrence of C3 fires. This design recommendation is consistent with the current BCA requirements which allow the designer to design a sprinklered shopping centre for a fire which presumes that the sprinklers have operated. However it is also necessary to *consider* the impact of an unsprinklered fire, to ensure that even in that situation, successful evacuation is possible.

The relative quantities of smoke generated by the various fire scenario groups are now considered.

11.2.2 Fires not Attended by the Fire Brigade (F_{SG1})

It can be assumed that the quantity of smoke generated by fires not attended by the fire brigade (F_{SG1}), is sufficiently small that a smoke control system is not required.

11.2.3 Fires Kept Small without Sprinklers (C1)

These fires are the majority of those reported to the fire brigade (~ 80%). They are not flashover fires, and although some vigorous burning may take place, their ability to produce smoke is limited. These fires are not seen as presenting a threat to the occupants of the building and will generally produce substantially less smoke (albeit more dense) than fires that activate the sprinklers.

11.2.4 Fires which are Controlled by Sprinklers (C2)

These are sprinklered fires and the volume of smoke generated will be a function of the following factors:

- type of combustibles (cellulosic; non-cellulosic)
- arrangement of combustibles (shelving; non-shelving)
- sprinkler arrangement in relation to fire (shielded; non-shielded)

The type of combustibles will have an influence on the quantity and type of smoke produced. Non-cellulosic combustibles will generally result in a greater quantity of dense black smoke than if only cellulosic materials are involved.

The arrangement of combustibles can also have a significant effect on the impact of sprinklers on a fire. Shelving (depending on its height and depth) will tend to shield the burning combustibles from direct extinguishment or action of the water; whereas, in the case without shelving, the impact of the water on the fire will be much greater.

The position of sprinklers in relation to the combustibles—particularly if water is prevented from getting to the *seat* of the fire (Figure 11.1)—will have an important influence on the quantity of smoke generated. Examples of this situation are illustrated by the Tests 1 and 3.

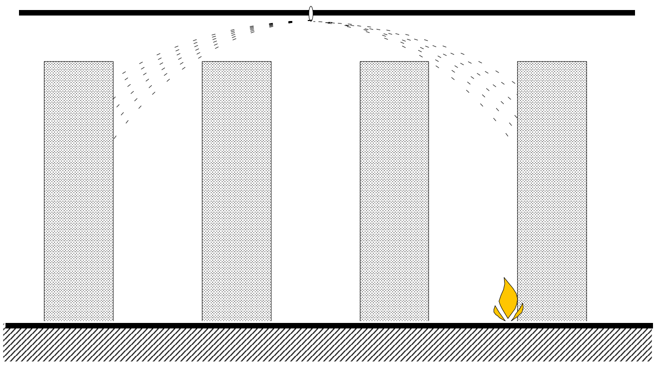


FIGURE 11.1 FIRE IN HIGH-RACK SITUATION

As far as smoke is concerned it is necessary to categorise sprinklered fires and then to determine the likelihood of occurrence of the various types of fire. Based on the results of the fire tests and some interpolation for situations which are midway between those for which there is little shielding of the sprinkler spray and those where there is significant shielding, it seems reasonable to categorise sprinklered fires as follows:

> *Category "C2-4" fire*—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 (Figure 11.1). The contents of the racks are assumed to be substantially non-cellulosic. These fires may be taken as identical to that experienced in Test 1. Expressions allowing the calculation of the smoke production rate are given in Appendix 11.1 and in Section 11.5.2.1.
>
> *Category "C2-3" fire*—On the other hand, if the situation is identical to that described above 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 "C2-2" fire*—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 “C2-1” fire—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 and are not considered to present a threat to the occupants. Of course some exhaust or venting would be required to finally remove the smoke from the building.

In considering the impact of sprinklered fires in shopping centre buildings, it has been assumed that these fires must be one of those described above, although tests have shown that fires where there are predominantly cellulosic combustibles will generate even less smoke (see Tests 10 and 11) than associated with a “C2-1” fire.

The likelihood of the various types of sprinklered fire in a shopping centre must now be determined. This has been estimated using the detailed information obtained from the shopping centre survey which gave a thorough picture of the situations and combustibles that exist with specialty shops and major stores and in related reserve or storage areas. The proportions of the total floor area occupied by each of these situations within a store or storage area can be used to estimate the probability of occurrence of a particular type of sprinklered fire. This can be done because the sprinklers are distributed more or less uniformly across the ceiling. On this basis, it has been possible to estimate the probabilities of occurrence of the different types of sprinklered fire (given a sprinklered fire) for specialty shops, supermarkets, major stores, reserve or storage areas. These probabilities are summarised in Table 11.1.

It can be seen that relatively few “C2-4” fires are expected and that the majority of fires will be “C2-1” type fires. This is confirmed by an analysis of several major shopping centres which indicates that the average probability of having an “C2-4” fire, given the occurrence of a sprinklered fire, is between 0.02-0.05. Thus various parts of the building can be designed for various types of sprinklered fires depending on the possible situations. *Major stores* with high shelving and where the sprinklers have not been located along the aisles between the shelves will need to be designed for a C2-4 fire, as will the *adjacent Mall* area of the building: however, other parts of the building can be designed for a lesser sprinklered fire if there is an absence of high shelving or the sprinklers better located. As will be later explained, the mall will be assumed to be a safe place for the occupants and may also need to act as a natural reservoir for smoke within the building. It therefore should be designed for the most severe sprinklered fire likely to occur in that part of the building.

☞ *For the purpose of considering the impact of smoke on the occupants of a building, it is recommended that the primary design fire be the relevant (C2-1—C2-4) sprinklered fire.*

TABLE 11.1 PROBABILITY OF OCCURRENCE OF TYPE OF SPRINKLERED FIRES*

Area of Fire Origin	*Type of Sprinklered Fire*			
	C2-4	*C2-3*	*C2-2*	*C2-1*
Specialty Shops (FSG6)	0.015	0.015	-	0.97
Major Stores (FSG3):				
Department Stores	0.02	-	-	0.98
Variety Stores	0.025	0.475	0.50	-
Major Toy Store	0.45	0.45	0.10	-
Major Sports Store	0.025	0.225	0.25	0.50
Supermarkets	0.025	-	0.025	0.95
Storage Areas[31]*:*				
Storage—major stores (FSG14)	0.50	-	0.50	-
Storage—Specialty Shops (FSG18)	0.015	0.015	-	0.97
Other Areas[32]*:*				
Structural Areas (FSG9 , FSG12)	0.25	0.25	0.25	0.25
Service/Equipment Areas (FSG21)	-	0.25	0.25	0.50
Service Facilities (FSG27)	-	-	0.95	0.05

* Assuming the occurrence of a sprinklered fire

11.2.5 FIRES NOT LIMITED TO AREA OF FIRE ORIGIN (C3)

These fires (ie. *FSG4* , *FSG7* , *FSG10* , *FSG13* , *FSG16* , *FSG19* , *FSG22* , *FSG25* , *FSG28*) are potentially severe with the possible rate of heat release reaching more than 40 MW. Fortunately, these fires are extremely rare.

☛ *Such fires can only eventuate when the sprinkler system has failed; however, their impact on occupant safety does need to be assessed.*

A C3 fire for the purpose of assessing aspects of building performance has been derived from the survey data [5] associated with the specialty shops. The fire is assumed to be associated with a specialty shop of average floor area, average ventilation and having an average fire load density. The following values were obtained:

- floor area = 104 m²,
- ventilation area = 10.5 m²,
- fire load = 23.7 kg/m² (~ 450 MJ/m²)

Assuming an ultra-fast growth rate, the heat release rate has been constructed based on the method described in [49]. This is shown in Figure 11.2.

It is considered that the choice of this C3 fire is justified on the following grounds:

- a C3 fire is a very rare event and therefore it is more appropriate to choose *average* conditions than extreme values.

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[31] This assumes that sprinkler heads have been located as recommended in Chapter 7 for areas where high racking.

[32] These numbers are based on an estimate of the smoke generating ability of the various fires.

- the fire is as severe as either of the non-sprinklered fires experienced during the test program (see Chapter 6).
- the fire is considerably more severe than any fire currently considered for assessing tenability of parts of the building.

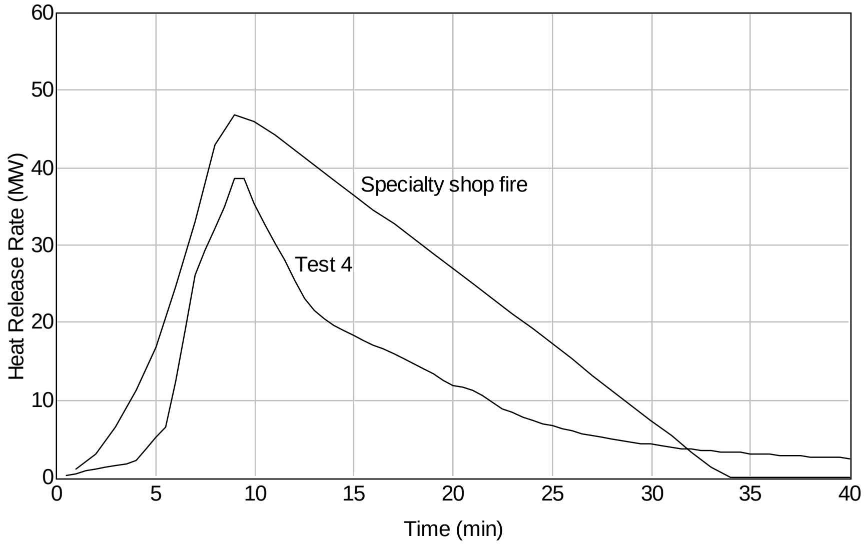


FIGURE 11.2 HEAT RELEASE RATE OF THE SPECIALTY SHOP FIRE

11.3 SMOKE VENTING AND EXHAUST

11.3.1 INTRODUCTION

The BCA requires smoke exhaust/venting systems for covered malls and for stores which open into a mall having a floor area exceeding 1000m^2. The capacity required for such systems is specified as part of the prescriptive requirements, although the system capacity can also be determined through rational analysis.

Venting and exhaust of smoke may be necessary to ensure that the smoke layer in parts of the building is sufficiently high to allow safe evacuation of the building. This section of the report considers the effectiveness of these systems. The capacity required is a function of many factors including the design objective (eg. “infinite” tenability for a “safe place” versus sufficient time to allow for evacuation), the volume of the enclosure, and the particular design fire.

A number of publications covering the design of smoke control systems for various situations are available [36,52-53]

11.3.2 TYPES OF SYSTEM

11.3.2.1 Venting

Venting through openings in the roof applies mostly to mall situations and is achieved through the provision of permanent openings (eg. at the sides of the roof) or through blades that are normally shut, but open when smoke or heat is detected. The blades may be motorised or mechanically released upon activation of a smoke or thermal detector. Thermal detectors may be in the form of fusible links.

The use of natural venting is a very effective way to extract smoke due to the fact that the natural buoyancy forces which drive the smoke upwards are a function of the fire size and temperature. This means that as the temperature of the smoke at the vent increases, the ability of the vent to extract smoke increases due to the increase in differential pressure. It also means that the rate of influx of fresh air to the fire (via doors and surrounding spaces) will be dependent on the size of the fire. Small fires will attract low volumes of air and this will have minimum impact on the growth of the fire at this early stage. In comparison, an exhaust system will result in generally constant air flow into the fire irrespective of the stage of growth.

Concern has sometimes been expressed that ambient wind conditions may interfere with the venting of smoke from a mall, resulting in the smoke being driven downwards. The provision of symmetrical venting or venting outlets which are not subject to the direct effects of wind will overcome this potential problem (see Figure 11.3).

In a mall situation, it may be necessary for the venting to be able to be activated by detectors close to the level of fire origin *and* at the vent level, to ensure that possible ambient temperature gradients within the mall do not unduly delay activation of the vents. Otherwise, it is possible that the high ambient temperatures at roof level may slow the movement of smoke towards the vents and the associated detectors.

11.3.2.2 Mechanical Exhaust Systems

Mechanical smoke exhaust systems can be part of the air-handling systems in a building or can be *almost* completely separate. In either case, the supply air must be controlled to ensure that it does not assist smoke getting to occupied areas and that the make-up air velocity at the fire is not too high (otherwise the fire size and spread may be magnified). Therefore, in the case of separate systems, there must be “communication” between the air-handling and exhaust systems.

Air-handling systems can be those which serve:

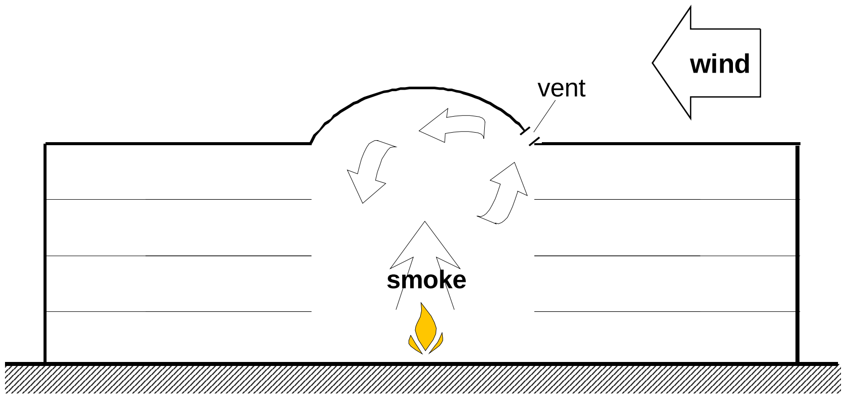
i. all buildings within the centre (a central air-handling system)

ii. a particular building within the centre (an individual system)

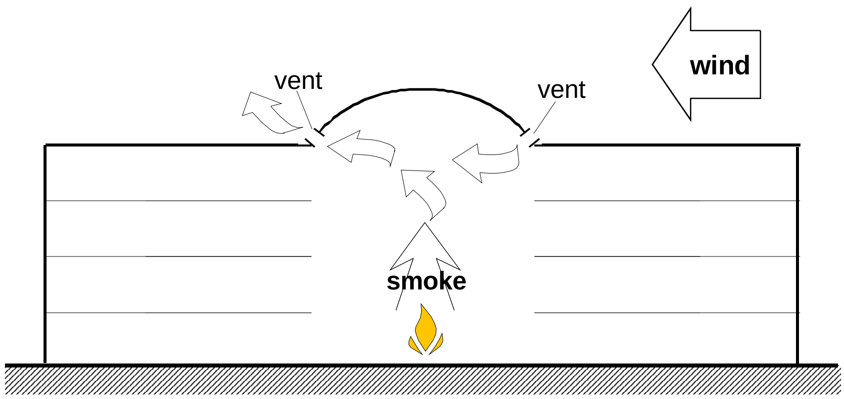
iii. a particular part of a building (a localised system)

For sprinklered shopping centres, system i. is rare, ii. is common; but iii. is increasingly common. This is certainly the case for the air-handling systems within a mall.

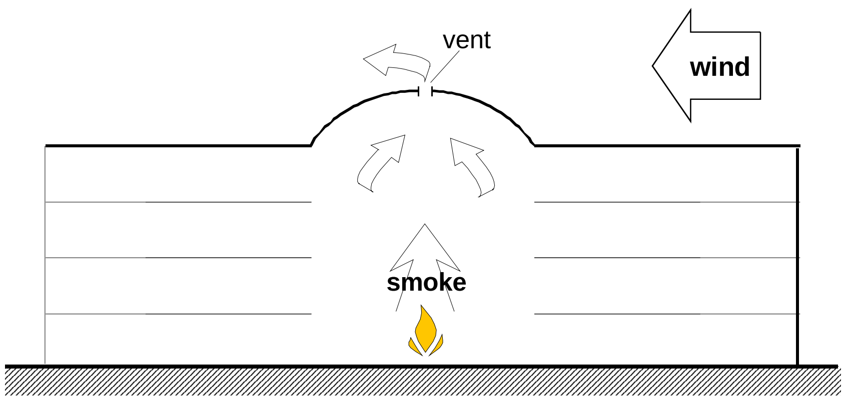
As far as *localised systems* are concerned, there are essentially two system designs (designated System Type 1 and System Type 2) and these are shown schematically in Figure 11.4. The main difference between the two designs is that System Type 2 uses the return air ductwork for the smoke spill system. Accordingly, Type 2 has a smoke spill damper that must be open for the exhaust fan to operate effectively. These systems are used in both malls and major stores and are chosen principally on cost.



a) asymmetric venting - possible problem



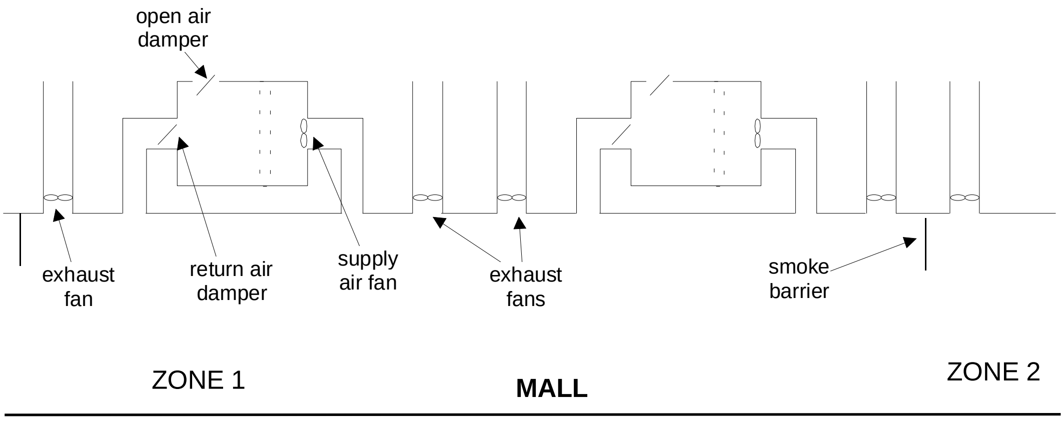
b) symmetric venting - possible solution



c) central venting - possible solution

FIGURE 11.3 POSSIBLE EFFECTS OF WIND ON VENTING OF SMOKE FROM A MALL

System Design Type 1
(elevation view)



System Design Type 2
(elevation view)

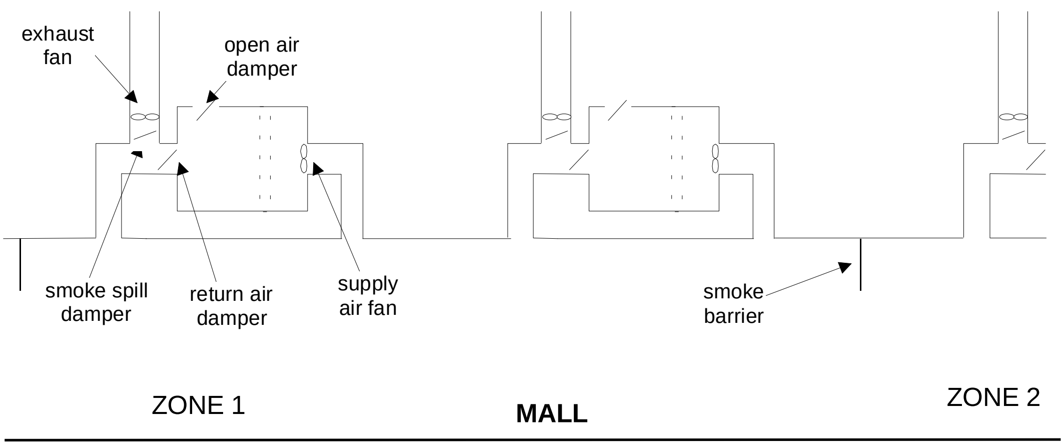


FIGURE 11.4 LOCALISED SMOKE EXHAUST SYSTEMS

As with natural venting, there are a number of design issues that need to be considered when designing mechanical exhaust for smoke extraction. Two of the significant ones are discussed below:

i. As the smoke passing through a fan heats up, its volume increases (ie. density reduces) and since fans are approximately constant volumetric flow rate devices, the ability of the fan to extract smoke will reduce. Thus, in the presence of hot smoke, extraction fans become less efficient. This matter is considered further in [52].

ii. Of course, the fan will draw in fresh air with the hot smoke and this will have a cooling effect on the smoke as it enters the fan. However, as pointed out by Morgan [53], it is possible that if the smoke layer is very thin, then the fan will mostly extract air from below the smoke layer (Figure 11.5) rather than from the layer itself. However, this will result in the smoke layer increasing in thickness and this, in turn, will improve the ability of the exhaust system to extract smoke. In the case of a C3 fire, this phenomenon is likely to be self-correcting as the smoke will remain buoyant as discussed above and the exhaust system become more efficient as the smoke layer increases. This raises the issue of smoke baffles and whether they are really necessary. Ref [53] gives equations for determining the depth of smoke baffles to allow the fans to efficiently extract smoke, but barriers sized using these equations are considerably deeper than those provided in current Australian practice.

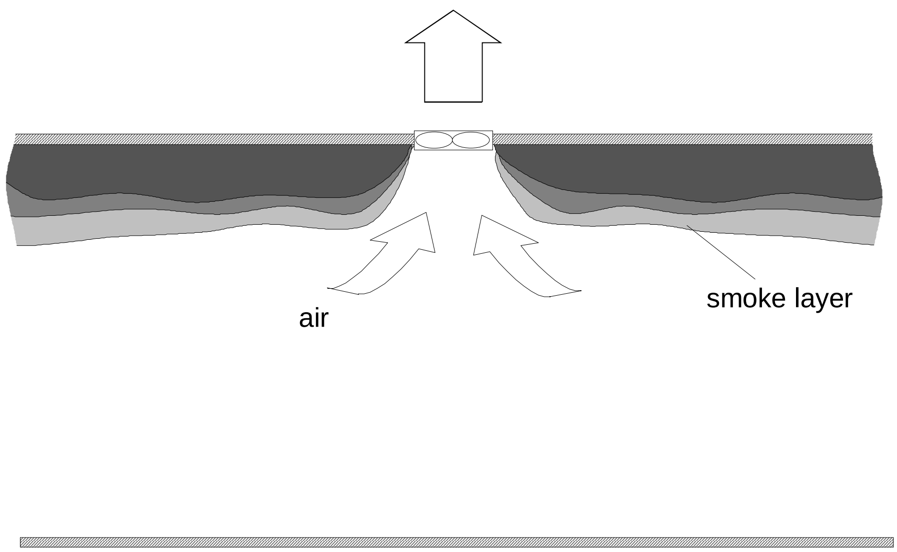


FIGURE 11.5 FAN EXTRACTING AIR FROM BELOW SMOKE LAYER

11.3.2.3 Smoke Baffles—Are They Necessary?

Smoke baffles are generally provided to contain the smoke so that it will not continue to move along horizontal surfaces or to ensure that the smoke forms a sufficiently deep layer to allow efficient extraction by a mechanical exhaust system.

As the smoke rises from a fire on the lowest level, air is entrained and this results in cooling of the smoke. The travel of smoke along a horizontal surface such as the roof of a mall will result in additional cooling due to convective heat transfer to the roof and further mixing with fresh air. The further that the smoke travels, the greater will be the mixing and the more dilute will be the smoke. At some stage, the smoke will become so dilute that it will not present a significant threat. This is certainly the case with many sprinklered fires. In the case of major stores, it can be assumed that the smoke from a significant sprinklered fire (ie. C2-2 - C2-4 fires) will remain sufficiently buoyant throughout an entire level of the store. This assumption is based on the observations during the fire tests and on the fact that these stores have relatively low ceilings (or soffits). In the case of the mall, and for the purpose of determining exhaust or venting requirements, it can be assumed that the smoke from such fires will not extend further than a total length of 60m along the roof—but will still be of a sufficient temperature to remain buoyant over this length. In practice, some smoke will continue to move horizontally beyond this length of 60m but that smoke will eventually become so dilute that it need not be considered as threatening smoke.

In the case of a C3 fire, the smoke will remain buoyant virtually throughout the entire mall due to its initially high temperatures.

The authors are not convinced that baffles are necessary for an effective smoke control system although it is recognised that they are often incorporated in order to limit the extent of smoke damage.

11.3.3 System Effectiveness

The *effectiveness* of smoke exhaust systems is now considered. As with sprinkler systems, effectiveness should be considered as a combination of the *efficacy* of the system and its *reliability*.

The *efficacy* of a smoke exhaust system is defined as the ability of a system to exhaust smoke assuming that it operates. The *reliability* of the system, on the other hand, is concerned with whether the system will operate in the first place. This is a complex matter due to the fact that failure of certain system components will not necessarily mean that *no* smoke will be exhausted—however, it may not be exhausted with the same efficacy as if *all* system components had operated.

The effectiveness of smoke exhaust systems has been considered in detail in an associated report [12] and the findings are summarised in this section. However, before giving a detailed summary of the findings, the following general observations are made:

- as the complexity of a system increases, its *effectiveness* reduces due to the reliability decreasing as the number of components increases. *Simple systems are best.*

- systems which utilise components needed for smoke spill, as part of their *normal* operation, will be more reliable than those that do not[33].
- the reliability of smoke exhaust systems has been generally regarded as low (< 50%)—this is probably justified in multistorey buildings with complex central air-handling systems for zone control. However, this need not be the case for *localised systems*.

A detailed evaluation of the effectiveness of two localised systems shown in Figure 11.4 has been undertaken in [12]. In that study, the reliabilities of the systems were assessed using a detailed fault tree analysis and took into account the possible interaction of systems in adjacent zones on system efficacy. In this case, 100% efficacy is defined as the ability of the system to exhaust at the rate that would be achieved if all parts of the exhaust system were operating as well *as possible* for the given set of local conditions (ie. smoke temperature, depth, etc). The results are summarised in Table 11.2 for systems which have been subject to *medium* levels of installation and commissioning and medium levels of maintenance. A higher level of commissioning and maintenance was found to offer little additional benefit.

TABLE 11.2 SMOKE EXHAUST EFFECTIVENESS*

Efficacy	*Probability of Achieving Efficacy Level*	
	System No. 1	*System No. 2*
< 25%	0.01	0.01
> 25% and < 75%	0.02	0.04
> 75%	0.97	0.95

* Effectiveness is a function of both reliability and efficacy

The effectiveness of more complex systems (central and individual systems) will generally be considerably less than the above systems and therefore their use should be avoided unless similar levels of effectiveness can be demonstrated.

As far as *venting* systems are concerned the following comments are made:

i. The use of fusible links, in combination with mechanically operated shutters in the mall roof, should be avoided due to the likelihood that sufficiently high temperatures will not be achieved to activate the fusible links.

ii. Similarly, the use of heat detectors on the mall roof is not recommended as sufficiently high temperatures may not be achieved to result in activation of the venting system.

iii. The reliability of a motorised venting system is a function of the reliability of the smoke detection system and the associated motors driving the shutters. It is important that the operation of the motors is tested on a regular basis as part of any normal maintenance program. If these systems are tested on a regular monthly basis, a reliability of 0.95

[33] Examples of this is where a common fan is used for both air-handling and smoke exhaust; or where smoke exhaust fans in the mall are used to purge stale air from the centre prior to opening.

may be adopted. If, on the other hand, they are rarely checked, then a much lower level of reliability will apply and the value of incorporating such systems must be questioned.

v. In situations where venting is available at all times, the reliability may be taken as 1.0.

11.3.4 CONCLUSIONS

Based on the definition of effectiveness given in the previous section, and assuming that average levels of commissioning and maintenance are undertaken, it appears that modern smoke exhaust/venting system—particularly those described in this section—can be assumed to have an effectiveness of around 95%. In the following sections it is assumed that these systems *work*.

11.4 DESIGN FOR EVACUATION

11.4.1 PRINCIPLES

The successful evacuation of the occupants in the event of a fire is a function of many factors but is most dependent on the provision of adequate paths of travel for the occupants. Based on the study of occupant behaviour and movement in Chapter 10, the following principles should be central to the design of any system for evacuation:

i. Familiar exit/entrance routes should be used for evacuation paths wherever possible.
ii. Sufficient capacity paths to allow efficient movement of the occupants should be provided.
iii. Sufficient paths should be provided to avoid the possibility of entrapment.
iv. The training of wardens should be sufficient to allow them to have a positive impact on any evacuation.

The design proposals presented below are based on the above principles.

11.4.2 DESIGN PROPOSALS

11.4.2.1 The Mall—A "Safe" Place

As asked in Chapter10: *under what conditions can a shopping mall be regarded as a safe place?* A mall is an example of part of a shopping centre building that *should* be designed to be a "safe" place given that, in the event of a fire in the shopping centre, the mall will provide a *natural haven* for people seeking to move away from the fire.

It is reasonable to propose that the mall be considered a safe place under the following conditions:

i. It has sufficient volume and/or smoke exhaust/venting to ensure that the smoke layer is maintained (to achieve "infinite" tenability) at an appropriate height above the highest level in the mall given the occurrence of the design fires nominated in Section 11.2.4.

ii. It has sufficient volume and/or smoke exhaust/venting to allow for the timely evacuation of the various levels in the presence of the C3 fire nominated in Section 11.2.5.

iii. Provision must be made such that the occupants can 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. Means to achieve this include open stairs, travelators/escalators, and direct access into connected safe places (eg. appropriately designed carparks, open space). 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
- be provided within 20m of each end of the mall
- each have an effective width[34] of at least 1.5m

The specific recommendations given in iii. are aimed at giving practical advice to avoid entrapment of the occupants in the event of a significant fire. Other specific geometric constraints for the mall are given in Section 11.5.3.3. Variations from these recommendations are possible but analysis specific to particular cases would be required.

The above proposals raised the possibility of escalators/travelators (or autowalks) being used for the purpose of moving people between levels within a mall in the event of a C3 fire. In that situation, upward moving escalators should be stopped as they will be transporting persons towards the top level which will be most affected by the smoke. The downward moving escalators should continue to run, except for any that become untenable due to the effects of the fire. Once occupants have been cleared from the now stationary, but previously upward moving escalators, these should be reversed in direction so that both escalators can assist in getting people from the upper levels. The same principles should apply for both escalators and travelators.

The management of escalators and travelators in an emergency is critical and is an essential role for shopping centre management. The development of a sound management plan with associated training drills is essential.

11.4.2.2 Adjacent Carpark—A Connected "Safe" Place

Shopping centre carparks, by virtue of their use, are usually large in area and well ventilated. The ventilation usually occurs naturally by means of the ramps (which are essential for easy access and egress for customers) and large wall openings. Such carparks provide a natural haven for occupants seeking to move away from a fire. Carparks relevant to this discussion will *not* be underground carparks which may differ substantially from the above ventilation conditions.

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[34] This refers to the actual width available to the occupants during evacuation and may be considered as being that provided by the use of both sides of an escalator.

Adjacent carpark levels provide a means whereby occupants can move out of the mall and down to street level by means of the wide aisles and ramps provided for normal vehicle access.

If a *sprinklered* fire occurs within the shopping centre such that the smoke vents into the mall, then it is unlikely that smoke will enter the carpark as it will be exhausted within the mall. The flames and smoke associated with such a fire are unlikely to have any influence on the carpark—irrespective of the presence of substantial boundary construction between the carpark and the mall. On the other hand, a C3 fire which is not controlled by the occupants or the sprinklers (a very rare fire), may result in some smoke passing into the carpark under certain circumstances. These circumstances and associated recommendations are as follows:

i. A fire in a specialty shop or store *opening directly* into the carpark. In this case the smoke may vent into the carpark and present a problem for people at an *upper level* who have decided to move into the carpark to escape the effects of the fire.

   In some cases, it would appear advisable not to allow the presence of significant openings between a store and a carpark and to require the wall construction between the two parts of the building to provide some reliable resistance to the passage of smoke.

ii. A fire in a shop *close to one of the entrances* into the carpark. In this case the smoke and hot gases will seek to enter the carpark through the entrance. This would present a problem, since although *this* entrance into the carpark may not be used by the occupants in the immediate vicinity of the fire (due to the proximity of the fire), other entrances into the carpark will be used and it is desirable to keep the carpark *substantially* free of smoke. It is considered that adequate separation can be achieved by means of normal glass doors between the carpark and the rest of the centre—provided the doors are drenched and are able to be closed (individually[35]) in the event of adverse conditions at that particular entrance to the carpark. One way of achieving this would be to:

   - activate closing of these doors through smoke detection *on the mall side* of the door, and
   - provide a line of fast response sprinkler heads on the mall side of the door, sufficient to shield the door glazing. These sprinklers should be connected to the *carpark system* which should be valved *separately* to the adjacent mall. The reason for this is that a C3 fire will only occur in this vicinity if the sprinklers in this area have been isolated—but in that case, the sprinklers at the door may not work either if they are connected to the same sprinkler zone. The likelihood of isolation of *both* sprinkler zones at the one time is extremely small.

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

Of course, some smoke will enter the carpark before and after activation (the doors are not sealed) but this will not present a threat due to the volume of the carpark and the natural venting noted previously.

It is not considered necessary to have a similar system for preventing smoke and hot gases getting into the mall given a fire in the adjacent carpark. The reasons for this are as follows:

- it takes some time for a fire to spread from one car to the next (due to the fact that the cars are physically separated and the combustibles contained within car bodies) and it is likely that the fire will be extinguished even before the sprinklers activate.
- cars cannot be parked near the door due to normal physical constraints and therefore it is difficult to see how a car fire could spread into the shopping centre.
- sprinklers in carpark have a reliability very close to 100% and smoke from a sprinklered fire (or other fire) will be vented by means of the normal carpark ventilation rather than finding its way into the mall.

Thus a carpark part of the building which is used as a safe place should be designed such that there is sufficient fire separation from retail parts of the building (see also Chapter 12).

11.4.2.3 Major Stores, Department Stores and Specialty Shops

As far as the egress requirements associated with major stores, department stores and specialty shops are concerned, it is 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 be considered 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.

The current exit requirements when applied within stores appear to ensure that movement times are low and that entrapment is most unlikely. This will be considered further in Section 11.6.

11.4.3 Determination of Evacuation Times

The calculation of evacuation times may be undertaken in accordance with Section 10.3. As indicated in that section, pre-movement times can be affectively ignored due to the fact, that in the areas closest to the fire, the dense smoke associated with a C3 fire will find its way rapidly throughout this part of the building—providing a cue for evacuation. To be specific, evacuation times can be taken as movement times, calculated:

i. For *major stores*, using Equations 10.2-10.4, provided adequate account is taken of queuing at exits; and it is recognised, depending on the location of the fire, that some of the exits may not be accessible. For the purpose of calculation it may be assumed that the movement of the occupants to the exits are distributed in proportion to the width of each accessible exit.

ii. For the *mall*, using an evacuation model (see Section 10.3.4.5) which takes into account the effects of queuing, the sequences of people movement, and the variation of population throughout the building. In these calculations the speed of travel may be taken as a function of the occupant density [21,48] (Figure 11.6).

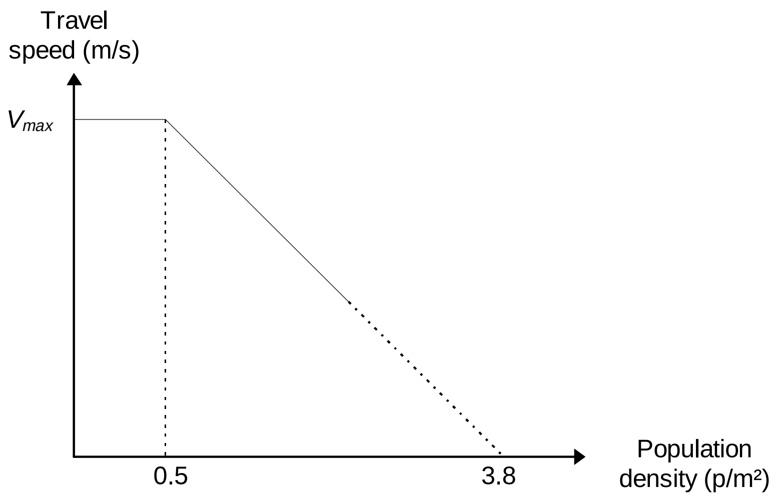


FIGURE 11.6 TRAVEL SPEED VARIATION WITH POPULATION DENSITY

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

The sequence of movements away from the fire-effected areas will be supported by wardens, who have a particular role to play in ensuring that a mall is evacuated in a timely manner in the event of a C3 fire. The desirable evacuation sequence is:

a) *Moving the occupants away from the fire-effected areas*— It should be noted that there will be a natural tendency for the occupants to move away from the smoke—and in the case of a shopping mall—there is much space for movement.

b) *Moving occupants from the fire-effected level*—If a fire occurs on a level which has direct access to the outside, then the occupants should be advised to commence evacuation of that level immediately. This will allow a more efficient evacuation of the upper levels as it will reduce queuing at exits to outside as people come down from the upper levels.

c) *Moving People from the other levels*—In shopping centre malls where the vertical passage of smoke is largely unimpeded, smoke will generally find its way to the topmost level. In this situation, the first level most likely to be seriously affected by smoke is the topmost level. The sequence in which the levels become affected is therefore a top-down sequence. Unless circumstances do not permit such a sequence or special circumstances prevail which may mean another level will be more seriously affected, the top-down evacuation sequence should proceed accordingly.

For the purpose of calculation of the time for evacuation of the mall, it may be assumed that 50% of the occupants of a major store move into the mall in the event of a fire, with the remainder using the emergency exits associated with the stores. All occupants of specialty shops will move into the mall.

11.5 DESIGN FOR SMOKE CONTROL

11.5.1 PRINCIPLES

The successful evacuation of the occupants, in the event of a fire, is also dependent on minimising the impact of smoke. As noted earlier, 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 the C2-2 to C2-4 sprinklered fires and C3 fires (unsprinklered), and control may be achieved through the provision of adequate building volume, venting or mechanical extraction.

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 followed by the smoke within that part of the building.

☛ *For the purpose of considering the impact of smoke on the occupants of a building, it is recommended that the primary design fire be the relevant (C2-1—C2-4) sprinklered fire.*

☛ *Although the occurrence of a significant C3 fire is very rare, the impact of the nominated C3 fire (see Section 11.2.5) on occupant safety must be considered.*

A variety of smoke untenability criteria may be suggested for these buildings in relation to the above criteria, however:

☛ *It is considered appropriate that smoke is maintained to a height of 2 m above the floor level.*

11.5.2 DETERMINATION OF SMOKE LAYER HEIGHT

As far as modelling the smoke layer height within parts of the shopping centre is concerned, the following is considered appropriate. The comments on the efficiencies of venting and exhaust in Section 11.3.2 should be noted.

11.5.2.1 Sprinklered Fires

In this case, due to the lack of other information, a formula derived from two of the fire tests in the experimental program has been used to determine the volume of smoke associated with these sprinklered fires (Appendix 11.1 and Section 11.2.4). This formula assumes that the enclosure (or reservoir) is a rectangular box with a leakage equal in area to 1-2% of the plan area of the enclosure. The volume of smoke for the two most severe fires that occurred in the test program is given by:

$$V = 4k_c\left(1 - e^{-t/240}\right) \tag{11-1}$$

where V is the smoke volume (m³),

t is the elapsed time (sec), and

$k_c = 3000$

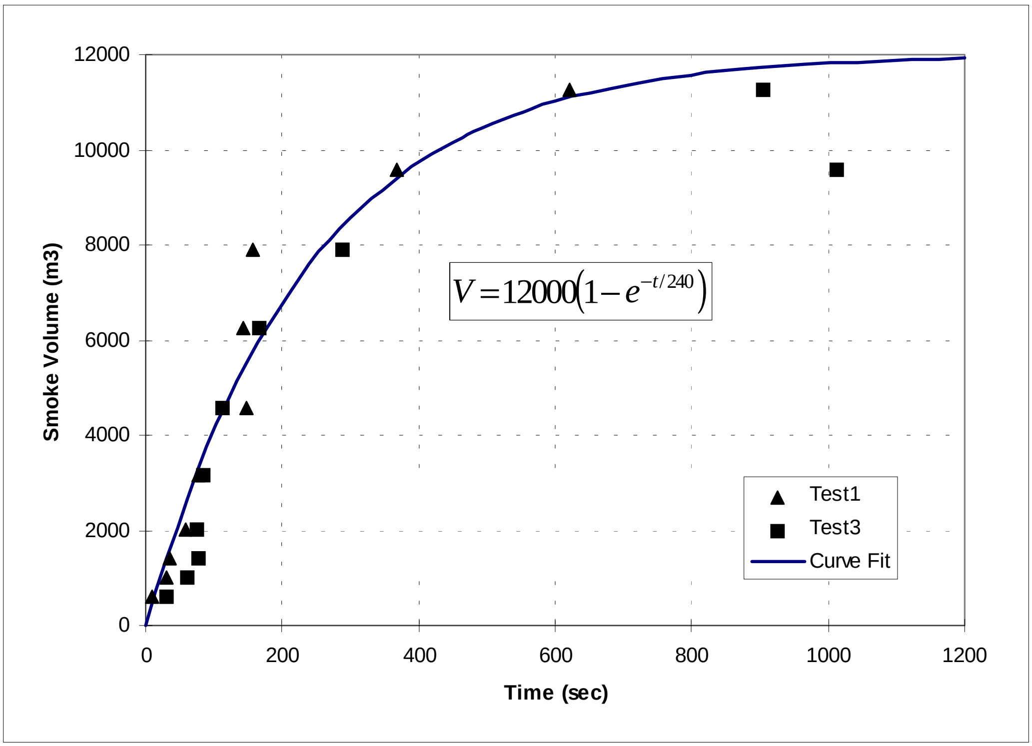


FIGURE 11.7 SMOKE VOLUME

Lesser sprinklered fires would be expected to generate less smoke (see Section 11.2.4). Assuming that the volume of smoke is in proportional to the fire size (as suggested in Section 11.2.4) the volume of smoke can be reduced proportionally (ie. for C2-3 fires, k_c estimated as 1500 and for C2-2 fires, k_c estimated as 750). It should be understood that the above expression for smoke volume is based on very limited data and caution should be exercised in using it.

The depth of the smoke layer as a function of the enclosure floor area is obtained by dividing the volume V by the floor area A (m²). These are shown in Figure 11.7 for a range of floor areas. To obtain the clear height, the smoke layer depth is subtracted from the enclosure height.

Equation (11-1) may be rearranged to express the time available for egress before the smoke layer descends to a critical level, as follows:

$$t_a = -240\, ln\left[1 - \frac{\left(H - h_{crit}\right)A}{4k_c}\right] \tag{11-2}$$

where $\left(H - h_{crit}\right)A < 4k_c$

and, t_a is the available egress time (s) < 720,

H is the internal floor to ceiling height (m), and

h_{crit} is the critical smoke layer height (=2 m)

The above equation is directly applicable to major stores as it is only necessary to show that there is sufficient time for evacuation. Depending on the height between the ceiling (or soffit) and the doors, it may be possible for the smoke to be contained within the store.

In the case of the mall however, it needs to be designed to be “infinitely tenable” in the event of a sprinklered fire. This may require the addition of vents and/or exhaust to ensure that the smoke is maintained at an acceptable level. However, account should be taken of the reservoir effect associated with adjacent stores and the roof of the mall.

11.5.2.2 C3 Fire

A zone model [50] or other formulae [36] can be used to estimate the smoke layer (hot layer) depth in an enclosure (major store or mall) in the event of a C3 fire. Account needs to be taken of the venting or exhaust provided within the enclosure. The temperature of the hot layer in this case is considered to be sufficiently high that it can be assumed to remain buoyant throughout the centre.

In this report, CFast [50] has been used and the use of CFast for modelling unsprinklered fires is discussed in more detail in [51].

11.5.3 APPLICATION OF DESIGN CRITERIA TO VARIOUS PARTS

Various parts of a shopping centre are now considered in more detail.

11.5.3.1 Specialty Shops

Due to the relatively small size of specialty shops, there is no need to consider the impact of a smoke layer within the effected specialty shop, as the time to move out of the shop into the adjoining mall area will always be less than the time for untenable conditions to be reached. Similarly, this applies to the adjoining specialty shops.

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.

11.5.3.2 Major Stores

The application of these design fires to major stores is distinguished by whether it is single level or multi-level.

(a) *Single Level*

In a single level major store within a shopping centre, the presence of a non-sprinklered C3 fire will present the greatest threat to the occupants. However, provided there is a significant opening into the mall through which the smoke can spill, the smoke layer will remain at greater than 2m above the floor. Alternatively, an exhaust system can be provided but it is unlikely that it will be able to cope with the quantity or temperature of the smoke.

In the case of a sprinklered fire, venting though the doorway into the mall will also provide a mechanism to control the height of the smoke layer.

The geometry required to contain the smoke from a C3 fire, to allow sufficient time for evacuation, will generally be sufficient to contain the smoke volume from a sprinklered fire. However, in the case of a small or sprinklered fire, some level of smoke extraction may be important to clear the smoke from the store—but the rate of extraction need not be chosen from a life-safety perspective.

(b) *Multi-Level Department Stores*

These buildings are potentially the most critical due to the presence of floors interconnected by escalators. In the event of a C3 fire on a lower level, smoke will travel up the escalator shaft (despite the presence of edge baffles) and this will prevent the escalators being used as a means of egress from the upper levels.

It is considered best to provide venting at the top of the escalator shaft, as this will ensure that occupants on the levels above the fire will become aware of the presence of the fire below and commence evacuation. The provision of such venting will also ensure that the store fills from the top down which is desirable from a fire-safety viewpoint. This concept is illustrated in Figure 11.8

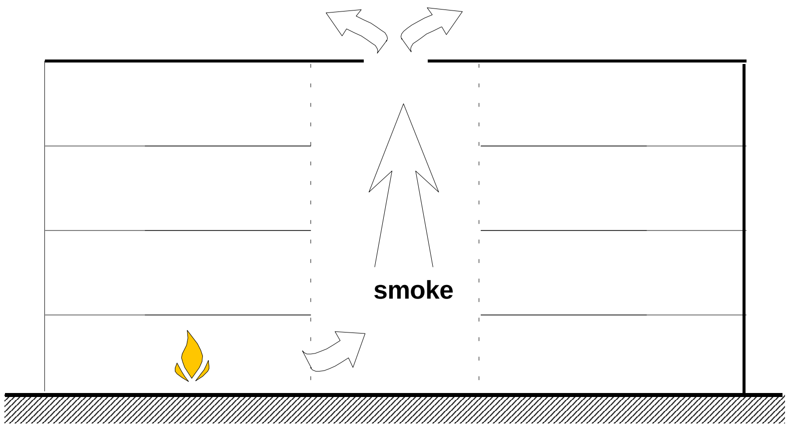


FIGURE 11.8 VENTING AT THE TOP OF ESCALATOR SHAFT

Once again, for the case of a small or sprinklered fire, some level of smoke extraction may be important on each level to clear the smoke from the store— but the rate of extraction need not be chosen from a life-safety perspective.

11.5.3.3 Mall

The mall may act as a smoke reservoir, in the event of a fire within an adjacent shop or store, or if there is a fire within the mall itself. The mall is part of the building that most occupants will move into as they seek to escape from the fire-effected part of the building. As explained in the Section 11.4.2, it must therefore be designed to be a safe place and adequate smoke control is necessary for this purpose. The design aspects associated with this are now considered.

As the exhaust/venting is provided at the roof of the mall, it is important to ensure that smoke can reach the roof from the lower levels.

☛ *This will be achieved if there is a sufficient number of adequately spaced openings within each walkway level in the mall.*

The above design requirement 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 75m.

The openings closest to the source of smoke where it enters into the mall will "attract" the smoke and minimise the horizontal movement of smoke along the walkway levels to other openings. Thus the *other* openings will be essentially free from smoke.

In allowing smoke to travel to the roof through openings in the walkway floors, it is possible that smoke may travel up through an opening which houses escalators or open stairs—which were noted in Section 11.4.2.1 as providing an acceptable means of moving people between levels in the event of a fire—and render these particular escalators/stairs as untenable. Thus it is necessary to ensure that there are sufficient *other* open stairs/escalators, or other means of egress, and this is the purpose of the specific design recommendations given in Section 11.4.2.1.

The presence of smoke within an opening that houses an escalator or open stair will act as a natural deterrent to the use of this facility. Nevertheless, the presence of wardens to provide direction to the occupants on each level is seen as central to any systematic evacuation.

Some further aspects of the design of the smoke control system for the mall are now considered:

C2 Fires

The smoke extraction system for the mall should be designed for the C3 fire and its capacity checked for the range of C2 fires for which the mall must be designed to be infinitely tenable. Each part of the mall should be designed to cope with the most severe sprinklered fire likely to be encountered in this part of the mall. The importance of positioning sprinkler heads to provide maximum impact on the fire (see Section 11.2.4) and of taking into account the reservoir areas associated with major stores or the ceiling space should not be underestimated. Sprinklered fires associated with the following situations will most commonly need to be considered:

- a major store where there is no high racking or where the sprinklers are positioned between the racks (C2-2 fire)
- a major store where there is racking and where the sprinklers are not positioned between racks (C2-3 or C2-4 fire)
- a specialty shop where there is high racking at the rear of the store but direct access for smoke into the ceiling void.

- a specialty shop where there is high racking throughout the store but where there is no direct access for the smoke into the ceiling void.

In the latter two situations, sprinklers should be positioned between the racks to minimise the potential for smoke generation. This will result in C2-2 fires.

C3 Fire

In this case, the smoke will be sufficiently hot that it may be assumed to remain buoyant throughout the evacuation period. Once again, account may be taken of the reservoirs associated with major stores. In the case of a fire originating in a specialty shop, failure of the ceiling within the shop will allow venting of the smoke into the ceiling space as well as into the mall.

11.6 CASE STUDIES

11.6.1 SINGLE LEVEL MAJOR STORE

Consider a single level major store as shown in Figure 11.9. For simplicity, the populated floor area of the store is taken as the entire floor area of 5062m^2.

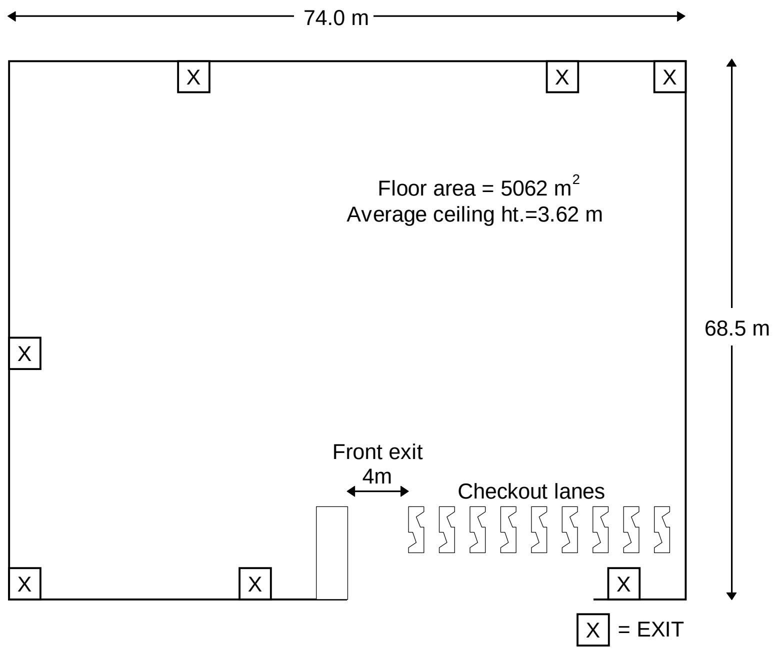


FIGURE 11.9 FLOOR LAYOUT FOR SINGLE LEVEL MAJOR STORE

Sprinklered Design Fire

It is assumed that the racking and sprinkler location in the store is such that a C2-4 fire may result. For a floor area of 5062 m² and a ceiling height of 3.62 m, the time for the smoke layer to reach 2.0 m is therefore

$$t_a = -240\, ln\left[1 - \frac{(3.62 - 2.0)\times 5062}{4 \times 3000}\right]$$

$$= 276 \text{ s } (4.6 \text{ min})$$

No account has been taken of the presence of openings into the mall which will increase this time.

Assuming that the store is located in a level directly accessible from the outside, the population can be based on 6 m²/person (Section 10.3.4.2). For the layout shown in Figure 11.9, the population is estimated to be 5062/6 = 844 persons. Assuming that all of the occupants will use the main entrance to exit the store, the time to exit the store is (using Equation 10.1),

$$t_m = \frac{68.5}{2 \times 1.2} + \frac{844}{1.3 \times 3.7}$$

$$= 204 \text{ s } (3.4 \text{ min})$$

There is therefore sufficient time for the occupants to evacuate from the store.

C3 Fire

The nominated C3 fire (see Section 11.2.5) is considered to occur within a storage enclosure which is connected to the public area of the major store via a 2m × 2m opening. The major store is then considered to connect to the mall or open area via a frontage opening of 8m × 3.6m. The height of the smoke layer is taken as the interface height determined from the zone model. This is shown in Figure 11.10.

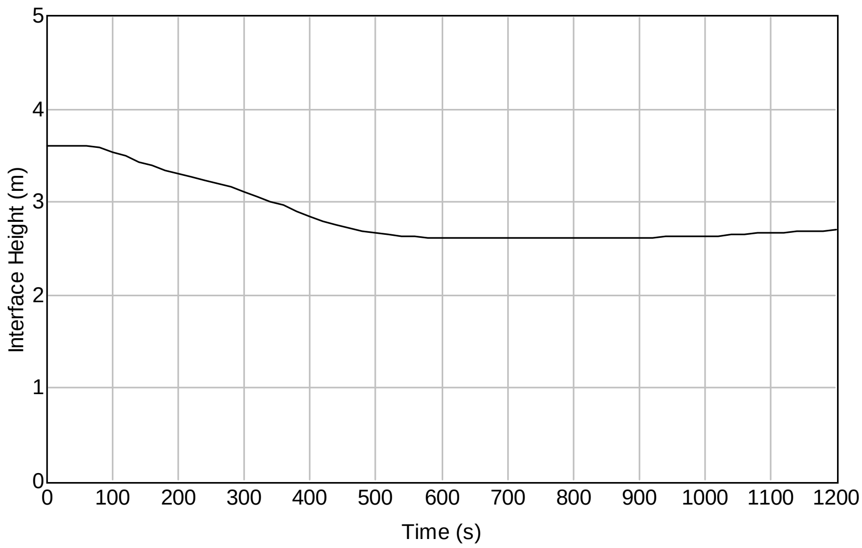


FIGURE 11.10 SMOKE LEVEL IN MAJOR STORE

It appears from Figure 11.10 that the smoke descends down to a height of 2.6 m above the floor and is therefore never critical.

11.6.2 DEPARTMENT STORE

Consider a multi-level major store as shown in Figure 11.11.

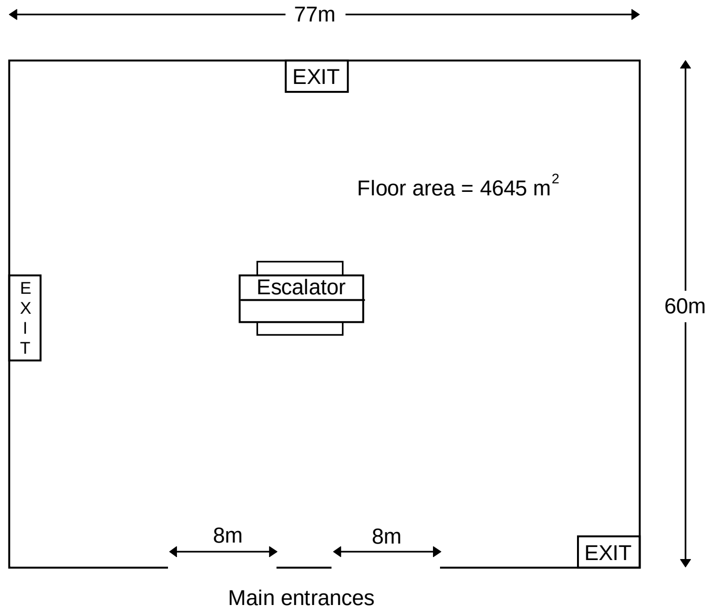


FIGURE 11.11 LAYOUT OF A MULTI-LEVEL DEPARTMENT STORE

The department store has four floors with a floor-to-floor height of 5 m and a ceiling height of 3.8 m from the floor. The floors are interconnected by a centrally located set of escalators.

Sprinklered Design Fire

In addition, relatively large gaps exist between the escalators and the floor as shown in the illustration. If the fire is located near the escalators, much of the smoke will find its way up through these gaps and around the escalators. Alternatively, if the fire is located at a remote corner of the floor, the smoke would disperse over much of the floor area prior to reaching the central escalators.

Assuming that the smoke from a corner fire will be contained within the fire level, the maximum depth of the smoke layer can be determined from Equation (11-2) as follows:

$$
\begin{aligned}
d_{max} &= \frac{4k_c}{A} \\
&= \frac{4 \times 750}{4645} \\
&= 0.65 \text{ m}
\end{aligned}
$$

Hence the height of the smoke is 3.8-0.65 = 3.15 m (>2.0) and is therefore not critical.

C3 Fire

The department store is considered to be connected to the mall or open area via a frontage opening of 8m × 3.6m at the first and second levels. It is assumed that a fire occurs on the ground floor. The plan area of the central escalator well is 50 m², and a roof vent having an area of 10m² is provided. The height of the smoke at each level is obtained from the zone model interface heights, and these are shown in Figure 11.12.

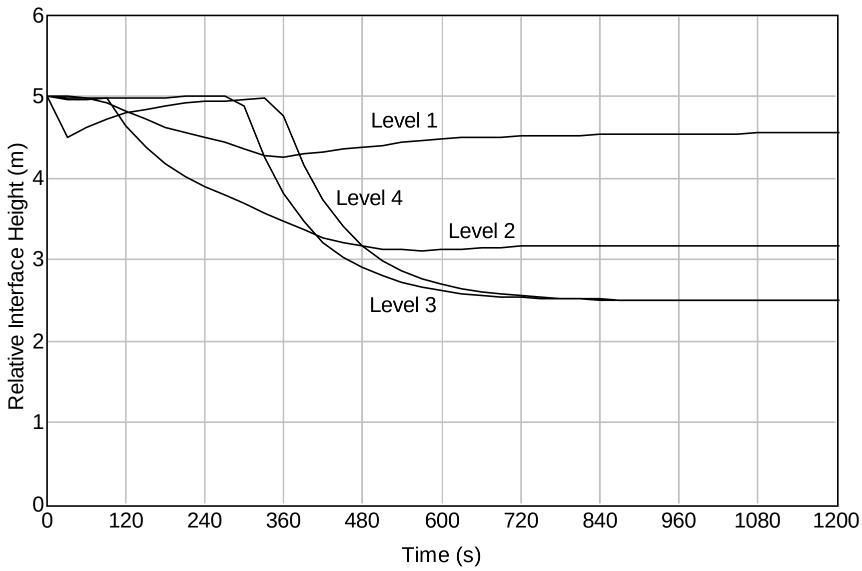


FIGURE 11.12 SMOKE LEVELS IN MULTI-LEVEL DEPARTMENT STORE

It can be seen that smoke in the uppermost levels, ie. Levels 3 and 4, descend to about 2.5m above floor level. Hence, the area of roof venting is adequate to maintain the level of smoke to safe levels.

11.6.3 MALL

Because the mall interconnects with other large spaces in the shopping centre building, it is reasonable to allow for these interconnections in predicting the level of smoke that can develop in the mall. These interconnections with other large spaces are based on the generic layout of the shopping centre complex shown previously in Figure 9.1.

The mall has four levels and the height between levels is 5 m. Due to the highly perforated floor in the mall areas, the space may be considered as a single volume. The topmost level is considered to have a vaulted roof such that the average height is approximately 7.5 m. With a floor height of 5m the overall height of the mall is therefore 22.5 m.

Unlike the previous cases, the smoke extraction system for the mall is firstly designed for the C3 fire and then its capacity checked for the range of C2 fires.

C3 Fire

Unlike the equivalent enclosure for the C3 fire in the major stores, the specialty shop is modelled to have a front entrance opening of 3.9m wide × 2.5m high. Furthermore, peripheral glazing at the shop front occupies an additional area of 10.5 m². This glazing is assumed to break and become fully dislodged when the gas temperature in the specialty shop reaches 300°C. This process is assumed to occur between 3.5 to 5.0 minutes into the fire.

The mall is considered to have vents along the sides of the roof providing a total vent area of 5% of the mall plan area. It is also assumed that 50% of the shop areas are open to the mall such that smoke may spill into these shop areas. In practice, it is likely that a higher percentage of shops will be open and will provide an additional reservoir to absorb smoke.

The fire is located at the ground floor of the central mall. Results from the zone model analysis are shown in Figure 11.13. The times to reach the critical heights in the Centre Mall area for the top level at 17.0 m from the ground floor is 225 s (3.8 min). The corresponding times for the East and West Malls are 290s (4.8 min) and 466 s (7.8 min) respectively. The times to reach the critical height for the third level for the Centre, East and West Malls are 1140 s (19.0 min), 1932 s (32.2 min) and 2020 s (33.7 min) respectively. These times do not account for the ability of the ceiling above the specialty shops to contain smoke following failure of the ceiling.

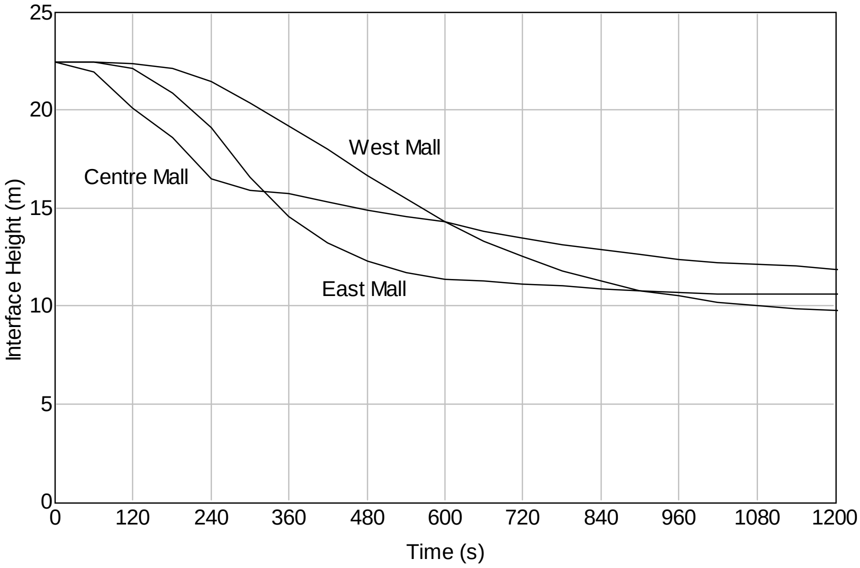


FIGURE 11.13 SMOKE LEVEL IN MALL

The evacuation times are now calculated.

In accordance with the design recommendations for the mall (Section 11.4.2.1), the maximum distance between escalators and stairs is 75 m. The estimated population area of the mall, including the specialty shops, over this length is 75 × 2 × (3+15) = 2700 m². The corresponding population is therefore 2700/10 = 270. The time for the occupants over this length of the mall to descend to the lower level, based on an effective stair width of 2 m is

$$t_m(\text{level 4}) = \frac{75}{1.2} + \frac{270}{2 \times 1.3}$$

$$= 62 + 104$$

$$= 166 \text{ s (2.8 minutes)}$$

Assuming it takes an additional 30 seconds to travel through the stairs to the level below, the time taken for the occupants on the level below to clear is

$$t_m(\text{level 3}) = 166 + 104 + 30$$

$$= 300 \text{ s (5.0 minutes)}$$

Hence, the movement times appear to be adequate.

The evacuation of the *mall areas* for the entire complex is simulated using EvacSim. Only movement times are modelled and it is assumed that a warden system is in place such that the evacuation proceeds from the top level downwards. The floor layout of the complex used in the simulation modelling is shown in Figure 11.14. The layouts for the two uppermost floors do not have direct access to the outside except for the exit to the car park off the East Mall.

The escalators are located in accordance with the recommendations in Section 11.4.2.1. It is assumed that the escalator in the central mall area is not accessible due to the effects of the smoke plume.

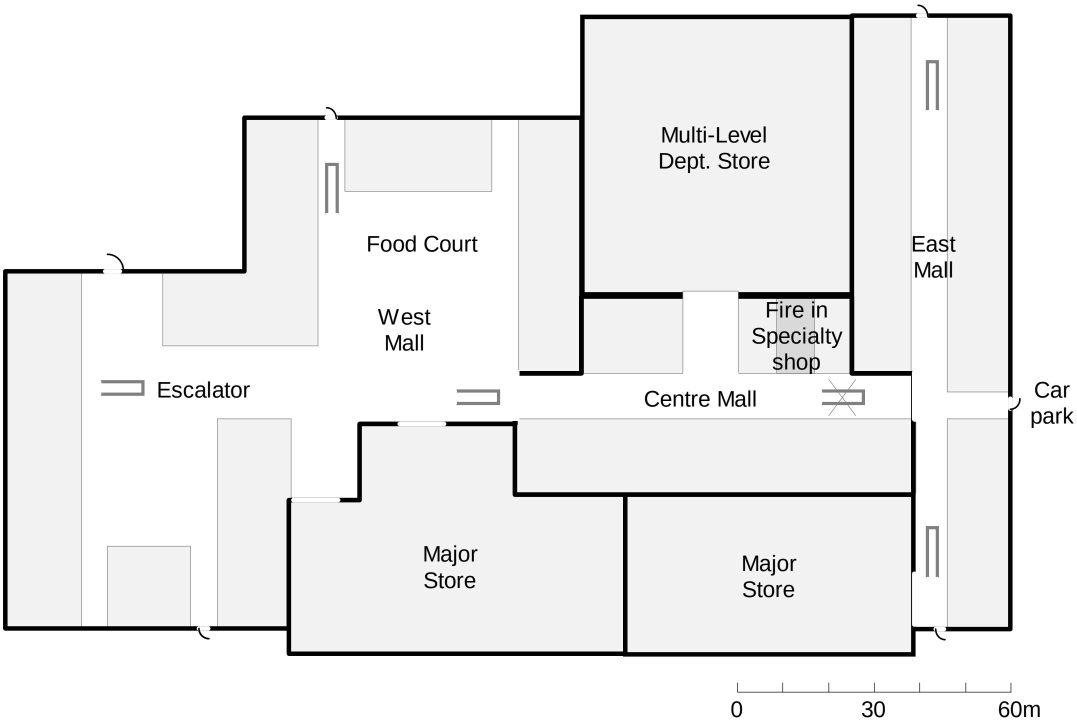


FIGURE 11.14. LAYOUT OF SHOPPING CENTRE USED IN EVACSIM

The entire complex altogether holds a total of 9578 occupants. The lower two levels have direct access to the outside and are therefore populated at 6 m²/person (2993 persons) compared with 10 m²/person (1796 persons) on the two uppermost levels. The shoppers in the two department stores discharge into the mall areas. For the multi-level department store, it is assumed that the shoppers are directed by the resident wardens to use the internal fire emergency exits. Pre-movement times have not been taken into account as it is considered that the effects of this very severe fire (ie. dense smoke in the mall) will result in almost immediate movement away from the fire. All occupants are instructed to exit as directed by the wardens in the appropriate sequence.

The results for the population variation with time for the top level and for the entire complex are shown in Figures 11.15 and 11.16 respectively. Figure 11.15 shows the population of the three mall areas in the complex. Figure 11.16 shows the aggregate population in each level. In Level 4, the occupants in the Centre Mall, East Mall and West Mall were cleared in 59 s (0.98 min), 180 s (3.0 min) and 209 s (3.5 min) respectively. Accordingly, all the occupants in Level 3 were cleared in 428 s (7.13 min). The entire complex is evacuated in 649 s (10.8 min). These times are compared against the critical times for evacuation in Table 11.3 below.

TABLE 11.3 SUMMARY OF AVAILABLE AND EVACUATION TIMES FOR LEVELS 3 AND 4

	Level 4 Malls			*Level 3 Malls*		
	Centre	*East*	*West*	*Centre*	*East*	*West*
critical time (s)	226	290	466	1140	1932	2020
evacuation time (s)	59	180	209	57	323	413

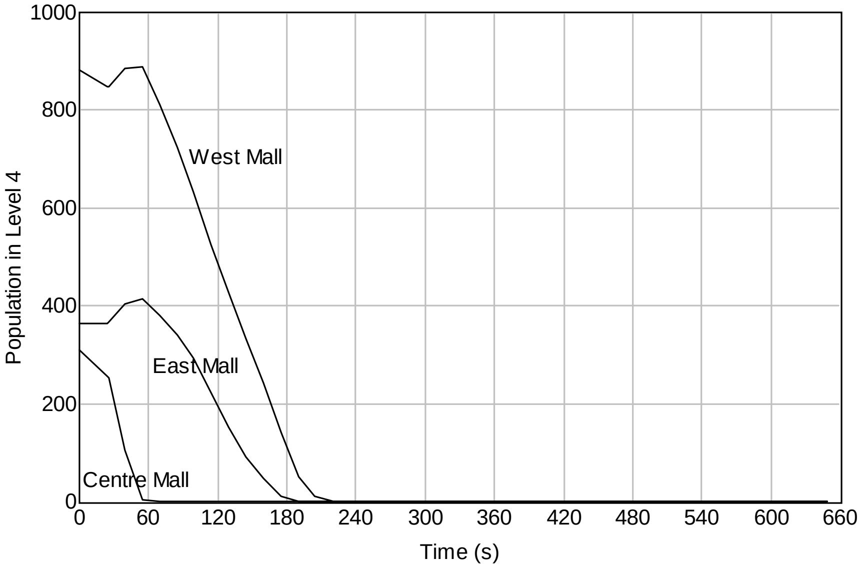


FIGURE 11.15. EVACSIM SIMULATION RESULTS - POPULATION IN LEVEL 4

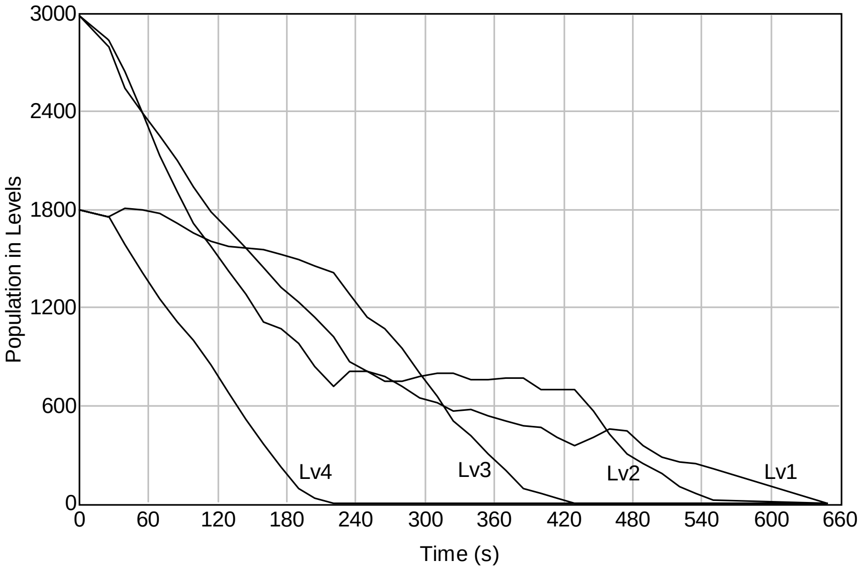


FIGURE 11.16 EVACSIM SIMULATION RESULTS - POPULATION IN LEVELS

Sprinklered Fires

Some of the sprinklered fire situations that may need to be considered, in terms of their potential impact on the mall, were outlined in Section 11.5.3.3 and are now discussed further.

a) a major store where there is no high racking or where the sprinklers are positioned between the racks (C2-2 fire)

For fires occurring in a major store, the large floor area would tend to provide an adequate reservoir in the ceiling area to contain the smoke prior to it spilling into the mall area. For a C2-2 fire, the smoke volume is 3000 m^3. Considering the major store in the previous case study (Section 11.6.1), the floor area of 5062 m^2 would require a ‘bulkhead’ to a depth of about 0.6m (~3000/5062) to contain the smoke. This requirement is readily achievable.

b) a major store where there is high racking or where the sprinklers are not positioned between the racks (C2-4 fire)

For a C2-4 fire, some of the smoke will eventually spill into the mall. Assuming that a bulkhead of 0.6m deep at the main entrance is provided, the volume of smoke spilled over into the mall is about 9000 m^3. For the mall considered above, the clear width between the shops is 12m. Assuming that the smoke does not extend more than 60m along the roof, the depth of the smoke layer is 9000/720 ≈ 12.5m. This is not satisfactory and therefore the provision of roof vents or mechanical exhaust needs to be considered. This impact of venting is further considered below.

c) a specialty shop where there is high racking at the rear of the store but direct access for the smoke into the ceiling void (a C2-2 fire assuming correct positioning of the sprinklers)

The space in the ceiling void above the specialty shop would usually extend across a number of shops. Assuming an average depth of void of 1.7m and that the void extends to an area of 75 × 15 = 1125 m^2, the void space therefore has a volume of about 1900 m^3. The volume of smoke spilling into the mall is therefore 3000-1900 = 1100 m^3. Assuming that the smoke does not extend more than 60m along the roof, the depth of the smoke layer is 1100/720 ≈ 1.5m. The clear height above the topmost floor is 7.5-1.5 = 6.0m (>2.0m), and is therefore adequate.

d) a specialty shop where there is high racking but there is no direct access for the smoke into the ceiling void (C2-2 fire assuming correct positioning of the sprinklers)

In this situation, nearly all of the smoke would spill into the mall. Hence the depth of the smoke layer at the mall roof is 3000/720 ≈ 4.2m. The clear height above the topmost floor is 7.5-4.2 = 3.3m (>2.0m), and is therefore adequate.

Some venting or mechanical exhaust will be required with the mall (at or near the roof of the mall) to remove smoke from a C2 fire.

An approach for assessing the adequacy of venting is now presented. For steady-state conditions, the expression for naturally vented smoke is given by [36]:

$$\dot{m}_{out} = \frac{C_d A_{vo} \rho_o \left[2g(h-z)(T_s - T_o)T_o\right]^{1/2}}{T_s^{1/2}\left[T_s + \left(A_{vo}/A_{vi}\right)^2 T_o\right]^{1/2}} \qquad (11\text{-}3)$$

where $\dot{m}_{out}$ = mass flow of vented smoke (kg/s)

C_d = discharge coefficient
A_{vo} = area of ventilation outlet (m²)
ρ_o = density of ambient air (kg/m³)
g = gravitational constant (m/s²)
h = floor-to-ceiling height of room (m)
z = (clear) height above floor (m)
T_s = average temperature of smoke layer (K)
T_o = ambient temperature of air (K)
A_{vi} = area of ventilation inlet (m²)

The equivalent volumetric flow rate may be expressed as

$$\dot{V}_{out} = \dot{m}_{out} / \rho_o \tag{11-4}$$

The density of air at ambient temperature is used in the above equation, as it will be little different to the smoke density associated with a well controlled sprinklered fire. If the area of the inlet ventilation is relatively much larger than the outlet area then Equation (11-3) may be simplified, and substituting Equation (11-4) gives:

$$\dot{V}_{out} = \frac{C_d A_{vo}\left[2g(h-z)(T_s - T_o)T_o\right]^{1/2}}{T_s} \tag{11-5}$$

In relation to the mall being considered in this section, sprinklered situation (b) will result in a substantial quantity of smoke spilling into the mall and venting or exhaust is required. Since venting has already been provided to cope with the C3 fire, this venting is utilised to cope with the major sprinklered fire. The venting provided in this example is equal in area to 5% of the mall plan area. This is equivalent to a vent area of 0.6 m² per unit length of the mall. Assuming that the smoke does not extend more than 60 m along the mall roof (see Section 11.2.3.2), the relevant vent area is 60 × 0.6 = 36 m². Considering an average rise in smoke temperature of 20°C for a C2-4 fire [11] and a discharge coefficient of 0.7, the maximum extraction rate (ie when the smoke layer is 2m above the highest floor level) is calculated as

$$\dot{V}_{out} = \frac{0.7 \times 36\left[2 \times 9.8 \times (7.5 - 2.0) \times 20 \times 293\right]^{1/2}}{313}$$

$$= 64.0 \text{ m}^3/\text{s}$$

The time at which smoke from a C2-4 fire reaches a volume of 3000 m³ is about 70 seconds (Equation 11-1) at which time it spills into the mall from the major store. The rate of smoke produced at this time and spilled into the mall is given by (Equation A11-3)

$$\frac{dV}{dt} = \frac{3000}{60} e^{-70/240}$$

$$= 37.5 \text{ m}^3/\text{s}$$

This value is less than $\dot{V}_{out}$ and because it is a decreasing function, the capacity of the extraction rate provided by the natural venting will be adequate.

12. BUILDING STRUCTURE—FIRE RESISTANCE LEVELS

12.1 INTRODUCTION

Section C (Fire Resistance) of BCA 96 [2] offers the following functional statements:

> "A building must be constructed to maintain structural stability during fire to-
>
> (a) allow occupants time to evacuate safely; and
>
> (b) allow for *fire brigade* intervention; and
>
> (c) avoid damage to *other property*."

and

> "A building is to be provided with safeguards to prevent fire spread -
>
> (a) so that occupants have time to evacuate safely without being overcome by the effects of fire; and
>
> (b) to allow for fire brigade intervention ……."

The above statements are really sets of detailed objectives which may be achieved in a variety of ways—sprinklers, fire-resistant construction, sufficient means of egress etc. Thus the building structure is not required to be fire-resistant for its own sake but rather as a means to providing a sufficient level of safety for the occupants. If a large fire is very unlikely, then the fire-resistance levels of the elements of building structure are less critical. In the following section, the probability of occurrence, and the impact on the building structure (and therefore on the building occupants) of the various fire scenarios are considered.

12.2 CONSIDERATION OF FIRE SCENARIOS

12.2.1 INTRODUCTION

As observed in Chapter 11, given 1000 fire starts in a typical shopping centre building with a soundly managed sprinkler system, 800 of these fires will be F_{SG1} fires, with 200 attended by the fire brigade: of these latter fires 141 will occur during occupied hours with 114.5 C1 fires, 26 C2 (sprinklered) fires, < 1 C3 (larger fires when sprinklers fail to operate).

As noted in Chapter 11, when considering the impact of smoke on the occupants, the *primary* design fire for these buildings should be a *sprinklered* fire (ie. a C2 fire) when the building has a soundly managed sprinkler system. This is also appropriate when considering the building structure.

☞ *In considering the impact of the building structure (when subject to fire) on the occupants, the* primary *design fire for these buildings should be a* sprinklered *fire (ie. a C2 fire).*

However, as noted in Chapter 11:

☞ *It is also necessary to* consider *the impact of a non-sprinklered fire, to show that even in that situation, successful evacuation is possible.*

12.2.2 FIRES NOT ATTENDED BY THE FIRE BRIGADE (F_{SG1})

It can be assumed that the effect on the building structure, of fires not attended by the fire brigade (F_{SG1}), is negligible.

12.2.3 FIRES KEPT SMALL WITHOUT SPRINKLERS (C1)

These fires are the majority of those reported to the fire brigade. They are not flashover fires, and although some vigorous burning may take place, their impact on floor and beam strength will be negligible. This assessment is made on the basis of fire test data [26] that shows that pre-flashover fires are not even capable of breaching a lightweight ceiling system in a room, and that lightweight steel members, even if directly exposed, will not experience a significant rise in temperature.

12.2.4 FIRES WHICH ARE CONTROLLED BY SPRINKLERS (C2)

The findings from the sprinklered tests conducted as part of this project indicate that even lightweight members will not be significantly affected by exposure to a sprinklered fire—even assuming that no ceiling is present (see Chapter 6). This is the case even when the sprinklers are not able to deliver water to the seat of the fire. This conclusion is also supported by the results of sprinklered tests conducted in other research projects [27-29].

It is understood, that in the past, an assessment of the building structure when exposed to a sprinklered fire has sometimes been based on a numerical analysis detailed as follows:

i. an assumed ultra-fast fire.

ii. an assumed time of activation of the sprinklers based on a simple fire model (numerical analysis).

iii. an assumption that one sprinkler head does not function.

iv. an assumption that once sprinklers are activated the heat output of the fire is maintained at a constant level.

It is clear from the tests mentioned above that these assumptions are quite unrealistic. In addition, the likelihood of one sprinkler head not activating whilst others do, is almost negligible. It is far more likely (but still very unlikely) that water will not issue from *any* of the sprinkler heads. This is the case covered in the next section.

12.2.5 FIRES NOT LIMITED TO AREA OF FIRE ORIGIN (C3)

12.2.5.1 Design Considerations

These fires (ie. F_{SG4}, F_{SG7}, F_{SG10}, F_{SG13}, F_{SG16}, F_{SG19}, F_{SG22}, F_{SG25}, F_{SG28}) are the fires that are potentially severe, as in many cases, flashover will occur. Such fires can only eventuate when the sprinkler system has failed. They are very rare as shown by Table 12.1 which tabulates the C3-1 and C3-2 fires for the building described in Section 12.2.1. This table shows the number of fires associated with different locations within the shopping centre.

TABLE 12.1 NUMBER OF C3 FIRES (GIVEN 1000 FIRE STARTS) WHEN SPRINKLER SYSTEM IS SOUNDLY MANAGED

	sales/ other		*structural*		*storage*		*services/*	*service*	*means of*
fire	*major stores*	*specialty shops*	*major stores*	*specialty shops*	*major stores*	*specialty shops*	*equip*	*facilities*	*egress*
C3-1	0.01	0.02	0.00	0.00	0.01	0.02	0.02	0.00	0.00
C3-2	0.02	0.04	0.00	0.01	0.02	0.03	0.02	0.00	0.01

As suggested in Chapter 8, it is the C3-2 fires that have the most potential to impact the building structure compared with the C3-1 fires which are confined to the room of fire origin. It will be noted from Table 12.1, that given the occurrence of a fire, the average probability of having a C3-2 fire in a critical area such as a *major store* (where fire spread is likely to be fastest[36]) is extremely small.

In addition to considering the various locations of these fires as given in the above table, it should also be recognised that that most severe position of a fire in a multi-level building, in terms of its impact on the occupants and the structure, is at the *lowest* level. For a building with a rise in storey of four, the average number of fires that occurs at the *lowest* level is *one quarter* of the values stated in Table 12.1. The average probability of a critical C3-2 fire in a major store at the lowest level is one quarter of the value stated above.

It is nevertheless necessary to consider the impact of such fires on the building structure and its role in allowing movement of people away from the fire-effected part of the building—and also in providing sufficient fire separation between "safe" areas within the building (see Chapter 11).

Practically all fires capable of affecting the building structure will occur within the sales and storage areas of specialty shops and major stores—because that is where the major fire load is located. The structural adequacy of these *parts* of the building must be maintained for at least sufficient time to permit movement of the occupants from the store or shops into the mall—assuming that the mall has been designed in accordance with the principles given in Chapter 11. The most potentially critical part of a shopping centre, in terms of the time taken for the occupants to move into the mall or other safe place, is a four-storey department store where *direct* horizontal access to street level, carpark, or mall, is not available at all levels. In such cases, the occupants may need to move down to street level by means of fire-isolated stairs within the department store. This will involve queuing at the exits which will require additional time before the occupants can reach street level. It is essential that the structural adequacy of this part of the building be maintained until evacuation is complete. The structural adequacy required for the various parts is dependent on the level and upon whether there is direct horizontal access at every level.

As explained in Chapter 10, the presence of dense smoke in the part of the building affected by the fire, will act as an effective cue in initiating movement of the occupants to a safer area. A C3 fire will result in large quantities of dense

[36] It is likely to be fastest due to the possible lack of surrounding construction which will act to slow the rate of fire spread. However, it should be noted that *even without such surrounding construction*, rapid spread will generally only occur with certain arrangements of combustibles.

smoke and it can therefore be assumed that movement to a safer area will commence at the stage of significant growth of the fire. In this context, pre-movement time can be ignored provided the C3 fire effects are considered from the start of significant fire growth. This is entirely consistent with the approach adopted in Chapter 11 which considered the evacuation of occupants in the event of a C3 fire.

An analysis of the longest times for movement to a safe place (ie. the time for the last person to reach a safe place) has been undertaken for a department store with a rise in storey of four. These calculations have been conducted for each level assuming the possibility of fire on any one level for the following building situations:

a) direct horizontal access to Safe Place at Level 1 only

b) direct horizontal access to Safe Place at Levels 1 and 2 only

c) direct horizontal access to Safe Place at Levels 1, 2 and 3 only

d) direct horizontal access to Safe Place at all levels.

For the purposes of analysis the following details and assumptions apply:

i. The plan area of each floor associated with sales (ie. not storage, stairs, lifts etc) is 5000m^2.

ii. Level 1 always has direct horizontal access to a safe place (refer Section 11.4.2).

iii. If direct horizontal access is available at a level, the total width available for occupant movement into the safe place is 6m (a low estimate) and that all of the occupants will travel to a safe place by this means.

iv. The occupants *on* and *above* the fire floor need to be evacuated as a matter of priority. The tabulated evacuation times assume that only these levels are evacuated.

    Note that the structural stability of the lower levels are not affected by the fire.

v. If direct horizontal access is not available on a level, then movement to a safe place (street level at Level 1) will be by the fire-isolated stairs. The stair widths required in this case are determined in accordance with Section D of the BCA including the area per person values given in Table D1.13. The movement time is the time taken for the occupants to descend the stairs and reach street level at Level 1. This is calculated using the alternative area per person values given in Section 10.3.4.2 of Chapter 10. It is assumed that the occupants remain within the stairs until they reach street level.

The building situations and assumed evacuation paths are illustrated in Figure 12.1. The calculated movement times are summarised in Table 12.2 and further explained in Figure 12.2.

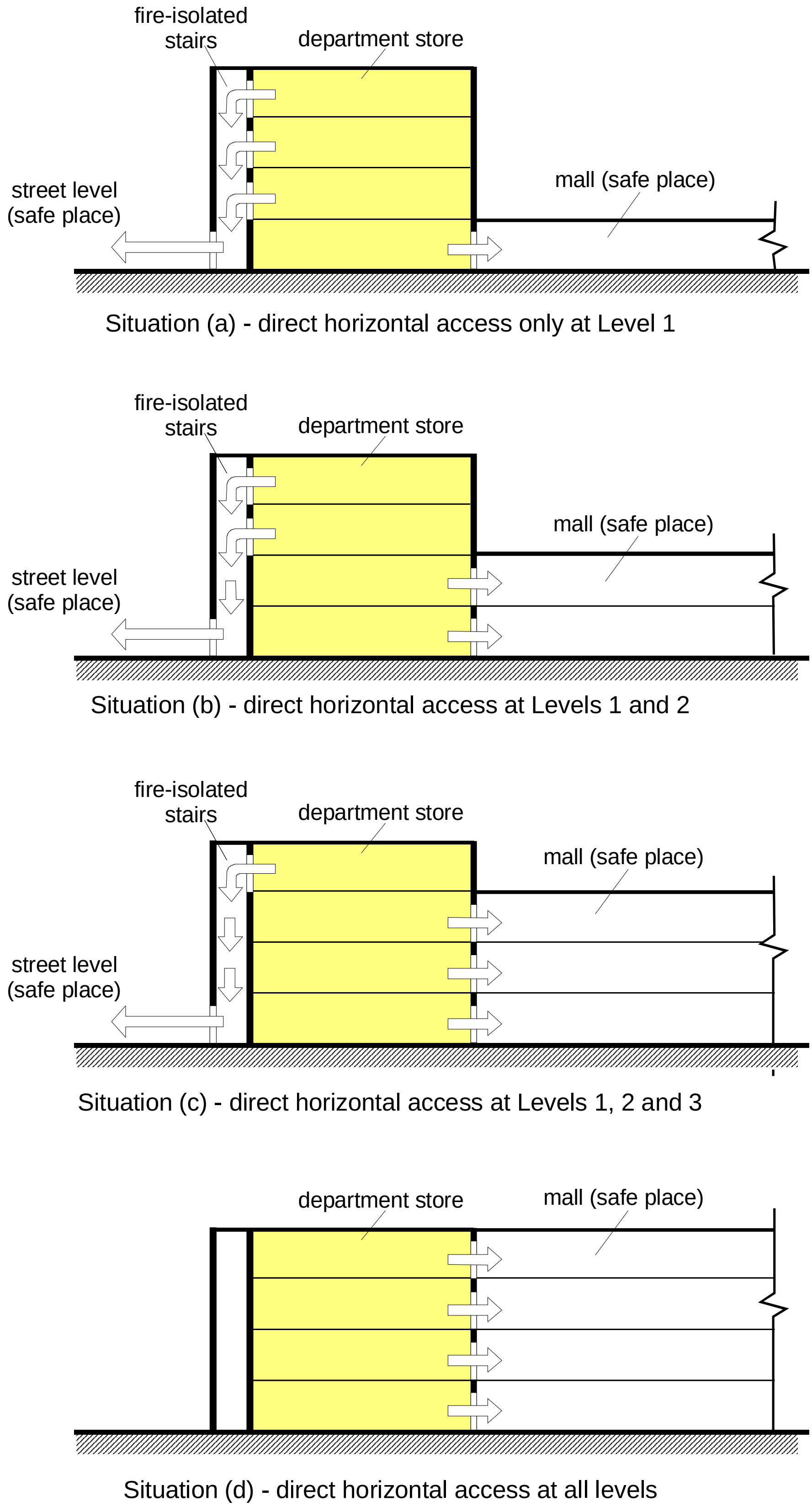
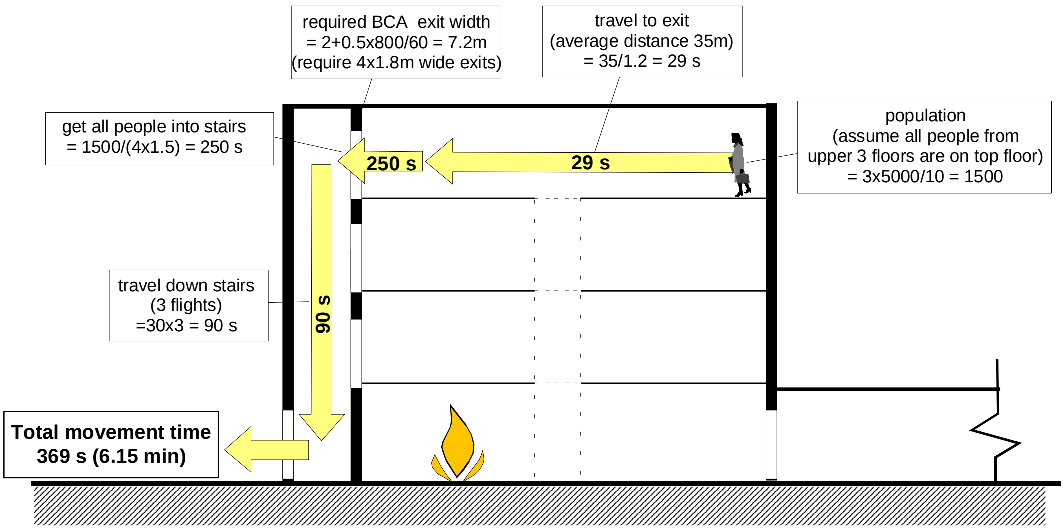
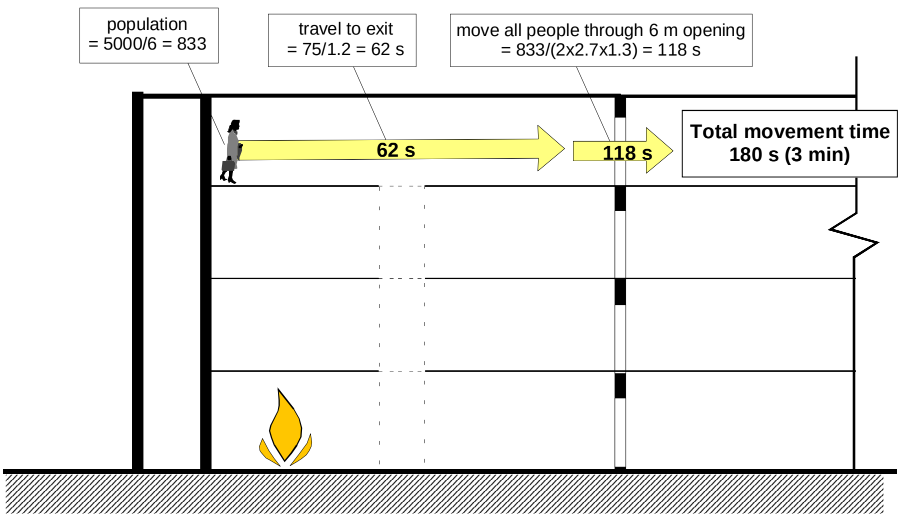


FIGURE 12.1 BUILDING SITUATIONS AND ASSUMED EVACUATION PATHS



Longest Movement Time for Building Situation (a)



Longest Movement Time for Building Situation (d)

FIGURE 12.2 CALCULATED MOVEMENT TIMES

TABLE 12.2 DEPARTMENT STORE — LONGEST MOVEMENT TIMES (TO A SAFE PLACE) (MINS)

Building Situation	*Fire Location*			
	Level 4	*Level 3*	*Level 2*	*Level 1*
Direct horizontal access to Safe Place at Level 1 only	3.25	4.7	6.15	6.15
Direct horizontal access to Safe Place at Levels 1 and 2.	3.25	4.7	4.7	4.7
Direct horizontal access to Safe Place at Levels 1-3.	3.25	3.25	3.25	3.25
Direct horizontal access to Safe Place at all levels	3.0	3.0	3.0	3.0

☞ *The fire resistance requirements should be related to the times given in Table 12.2.*

☞ *Floors (including beams) should have sufficient fire-resistance to allow direct movement of the occupants within* ***the fire level and those directly supported by the floor above the fire*** *into a mall, carpark, street, or into a stair shaft, as the case may be.*

The fire resistance required for a floor will generally be less than that required for a column as it is only necessary to allow for movement of the occupants on the floor *directly* above the fire and on the fire floor. Reasons for this are discussed in Section 12.2.5.2.2.

☞ *Columns (and loadbearing walls) associated with a particular level should maintain structural adequacy until the occupants on this level and those* ***above*** *have moved to a safe place.*

Thus a greater fire resistance may be required for the lower columns in the building. This is illustrated by two examples::

Department Store with direct horizontal access to a Safe Place on Level 1 only.

In this case, the occurrence of a fire on the top level (Level 4) will only affect the occupants on that level and failure of a column on that level (should it occur) will not affect the structure of the levels below. Therefore the maximum fire resistance required for the columns within the top level should be such that the occupants have sufficient time to enter an exit stairway within the store and reach ground level. If the fire is at Level 1 however, it will be necessary for the columns *at this level* to have a fire resistance sufficient to allow movement of all of the occupants on the three upper levels to ground level by the fire-isolated exits.

Thus, in the case of *this building*, the fire resistance of the columns should be least at the top and greatest at the bottom of the building.

Direct horizontal access to Safe Place on all Levels.

In this case it is only necessary for the columns to have a fire resistance sufficient to permit movement to a safe place on any level.

☛ *Adjacent carpark levels designed as safe places (see Chapter 11) should be designed such that the boundary construction provides adequate fire separation.*

The fire resistance period required for this boundary construction should be related to the time for movement of people within the carpark levels to the ground floor. This is estimated as being less than 10 minutes.

Aspects of the performance of the building structure when subject to C3 fires are now considered.

12.2.5.2 Impact on the Building Structure

12.2.5.2.1 C3-1 Fires

These are fires which have been restricted to the room of origin. They are not as severe as C3-2 fires—otherwise they would have spread beyond the room of origin. They are therefore not as severe as C3-2 fires and discussion of their impact may be considered to be covered by that of the C3-2 fires.

12.2.5.2.2 C3-2 Fires

These fires are those where mitigating influences such as occupants, sprinklers or enclosures are not able to restrict the development of a fire to the enclosure of fire origin. As noted previously, they are extremely infrequent in sprinklered shopping centres. These fires are potentially the most serious fires as they are capable of having an impact on all levels of that part of the building.

As discussed later, in Section 14.5.4.2, these fires include those which may eventually spread throughout a major store or spread beyond several specialty shops. It is recognised that once this stage is reached, it will be very difficult for the fire brigade to have much impact. Based on the results of fire tests conducted as part of this project it is known that C3-2 fires may be in excess of 40MW with air temperatures exceeding 1200°C. In considering the impact of these fires on the building structure the following facts about structures and shopping centre buildings should be noted:

i. As the fire begins to affect the structure (but well before it is seriously affected) the effects of high air temperatures will be experienced by the occupants of the storey above the fire due to movement of the floor and noise associated with the effects of thermal expansion. Although these movements will be small, the human body is very perceptive of movement[37] and the occupants on the floor above, if they have not already started to move to the exits, are likely to be startled and alerted. It is almost certain however, that the smoke associated with such a fire would have resulted in initiation of evacuation of this part of the building

[37] That this is the case is well recognised in structural engineering where particular care is exercised in designing buildings that do not respond to the action of people walking on the floor. The effects associated with thermal expansion of part of the building are much more significant.

by this time. However, movement of the structure would be an important *reinforcing cue*.

ii. Due to the plastics content of the combustibles in shopping centres, flashover fires may have all of the characteristics of a hydrocarbon fire—with very rapid temperature rise and very high temperatures. Such fires are quite different from those associated with the standard fire test, AS1530.4 [30], and may impact on materials quite differently. Conventional forms of construction have generally only been tested under standard “cellulosic” fire conditions and are likely to perform differently when subject to a substantially more rapid heating environment. This was evidenced during the tests when it was noted that extensive spalling of the concrete floor *upon* which the fire tests were conducted occurred. Had such a floor been located above the fire, then even higher temperatures would have been experienced by the concrete and the spalling exacerbated. However, even this is unlikely to result in total collapse of this part of the floor as it will continue to resist the applied loading through membrane action (see Figure 12.3).

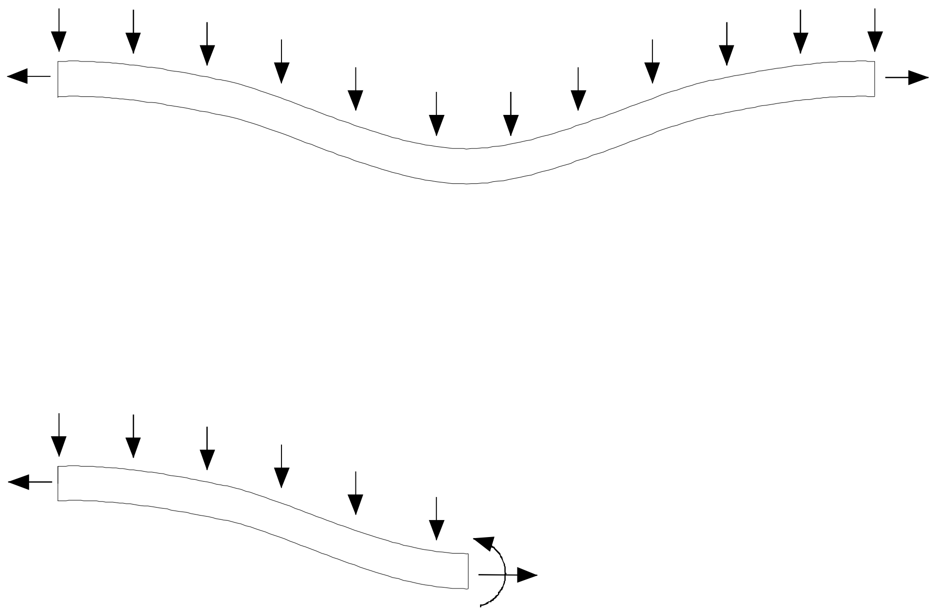


FIGURE 12.3 MEMBRANE ACTION

☛ *Thus floors,* irrespective of the material of construction, *could be expected to undergo large deformations.*

As the temperature of a flexural member increases, its strength and stiffness are reduced and its deflection increases. This is often magnified by greater heating of the bottom of the beam than the top, with the resulting differential expansion causing the beam to deflect downwards. As the temperature continues to rise and the level of deflection increases the load carrying mechanism (which has predominantly been by flexure or bending) becomes increasingly catenary action with the beam acting like a cable between supports. Provided the ends of the beam are restrained this mechanism will eventually carry the imposed loads, albeit with large beam deflections.

Generally, the presence of catenary action (and membrane action of the slab) as described above, may be expected to allow the parts of floors that are subject to intense fires from below to have a fire-resistance which is significantly greater than that calculated using simplified methods such as those given in AS4100 [31]. This form of behaviour was illustrated in Test 4 of this project where the substantial load applied to the steel beams was supported (with significant permanent deflection of the beams) despite the fact that the steel beams directly above the fire reached temperatures of 1200°C (see Figure 12.4). Beams associated with this floor construction were lighter than those likely to be incorporated in shopping centre floor construction. Another example of this behaviour was obtained in one of the “real” fire tests conducted at the Building Research Establishment’s fire test facility at Cardington in the UK. The facility includes an 8 storey steel-framed building which is being used for research into the behaviour of steel structures in fire. In this test program, a loaded composite floor system incorporating unprotected steel beams was exposed to a long duration fire (see Figure 12.5) with the steel temperatures rising to well above 700°C. The floor system after the test is shown in Figure 12.6. Beam sizes were similar to those which would be incorporated in shopping centre buildings if constructed as Type C construction. It is estimated that when subject to a C3-2 fire (the more serious of the C3 fires), such a floor system would survive for more than 15 minutes.

iii. Failure of part of a floor will not result in large deformations of *parts of floors directly above the fire-effected part of a floor*, provided the structural adequacy of the columns in this fire-effected part is maintained.

iv. What structural adequacy is required for columns at the *lower* levels of a building? The longest time for evacuation (6.15 minutes) of the multi-level department store considered in Section 12.2.5.1 (see Table 12.2) can be used to obtain the required fire-resistance level for these columns. This is reasonable since only *part of this store* would be affected by the off-loading of several local columns, and a department store is only *part* of a shopping centre building. Hence, evacuation of other parts of the shopping centre building can take place since the structural adequacy of these parts is independent of that associated with the fire-effected part[38].

[38] Progressive collapse will not occur in these buildings as they are framed structures which are wide with respect to their height. Progressive collapse—or the collapse of a building after the removal of one critical element—is applicable to tall buildings which are constructed as boxes using panel construction not capable of framing action (eg Ronan Pt Flats disaster in the UK [32]) but only axial force or shear resistance.

FIGURE 12.4 TEST STRUCTURE AFTER TEST 4

FIGURE 12.5 CARDINGTON FIRE TEST

FIGURE 12.6 THE FLOOR SYSTEM AFTER CARDINGTON FIRE TEST

The behaviour of steel columns when exposed to the recommended C3 design fire (see Section 11.5.4.2) is considered in Appendix 12.1. For a column to provide sufficient fire resistance to maintain structural adequacy for the time it takes for people to evacuate this part of the centre (ie. the department store), the columns should have an FRL of 15-30 minutes.

v. In Chapter 7, it was recommended that the sprinklers for each level of the building be separately valved. If this is the case, then the chance of two zones, located one above the other, being isolated at the one time is extremely small. Thus the sprinklers on the level *above* the fire will have some impact on the fire in the unlikely circumstance that the fire breaks through to the next level. This part of the building would have been well and truly evacuated by the time such an event occurred.

The shopping centre buildings being considered in this project are large in plan area compared with their height, being the opposite of high-rise buildings which are tall and narrow. As a result there are very many columns providing support to the floors as illustrated by Figure 12.7 which shows the photograph of a small scale model of part of a four storey shopping centre building. Failure of a column, or even a number of columns, will not result in collapse of the building. Thus, although parts of the buildings may undergo very substantial deformation given sufficient time and fire exposure, the overall stability of the building will not be impaired.

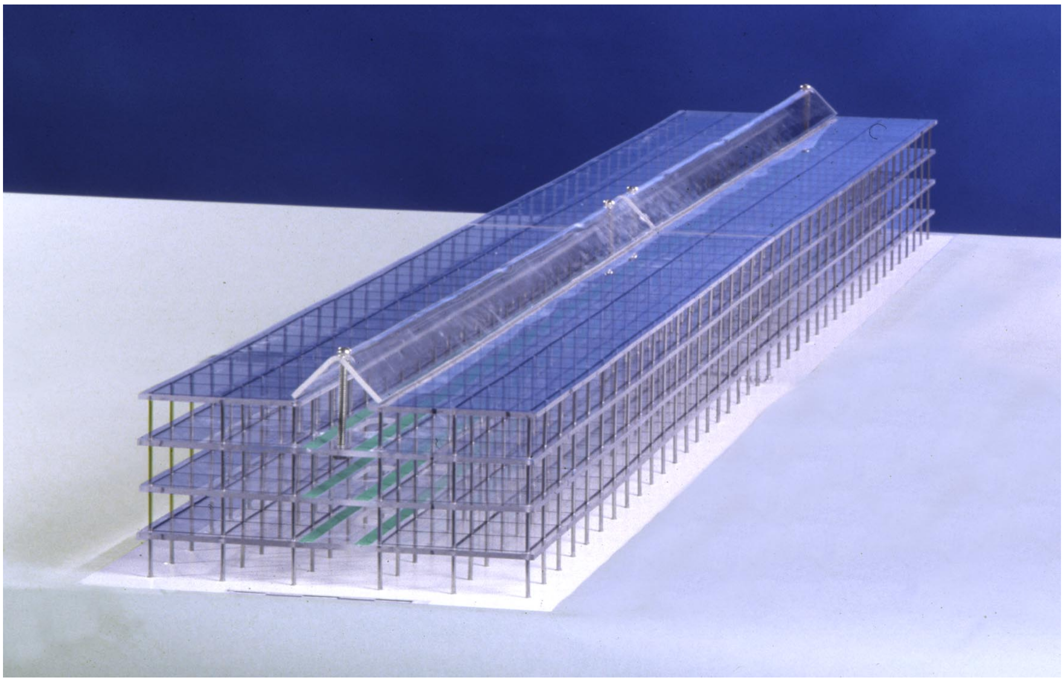


FIGURE 12.7 A SMALL SCALE MODEL OF PART OF A FOUR STOREY SHOPPING CENTRE BUILDING

12.3 LESSONS FROM CASE STUDIES

As noted previously, deaths in shopping centre buildings are rare and it is hard to find examples where structural failure has been a contributing factor to deaths in buildings, as in the majority of situations, people have evacuated the relevant part of the building before the fire is sufficiently intense to lead to failure.

The most notable fire in a shopping centre where there was significant loss of life was that associated with L'Innovation in Belgium. This fire was reviewed in [7]. Detailed accounts of the fire and aspects of the building are given in [33,34]. To re-iterate the situation associated with this building, there were:

- insufficient or blocked exits
- combustible ceiling tiles and other combustible finishes
- no sprinklers or detection
- inadequate fire fighting facilities within the building
- major rooms without sufficient exits (the restaurant where over 200 people perished)

The building had a rise in storey of 5, and a height of 27m and was essentially a large atrium building with each storey having a floor area of 9100m^2 and interconnected by a void extending the height of the building.

The fire occurred during the lunch break and was said to have spread rapidly, both vertically and horizontally, through voids which connected the various levels, and across the ceilings—the decorative combustible ceilings assisting horizontal fire spread. It started on the ground floor. The fire brigade arrived 5 minutes after receiving a call but noted that upon arrival "the building was engulfed in flames". At this point survival within the building was an impossibility—irrespective of structural performance.

The building structure was constructed of unprotected steel, concrete and masonry construction. Unprotected steel (beams and columns) was provided throughout one entire corner of the building. This collapsed 20 minutes after the fire brigade arrival. In another corner of the building, unprotected steel was used for the ground and first floor. This part of the building collapsed two hours after fire brigade arrival. More that two hundred people perished in a restaurant on the third floor due to smoke inhalation and the fact that there were insufficient and inadequate egress paths from this enclosure.

The behaviour of the building structure did not contribute to the deaths.

12.4 CURRENT REGULATORY REQUIREMENTS—IMPLICATIONS

The functional statements given in Section 12.1 do not state *how* the statements are to be achieved, but one acceptable solution is clearly the deemed to satisfy requirements of Part C1. It is informative to consider the implications of these requirements of sprinklered shopping centre buildings.

12.4.1 DEEMED TO SATISFY REQUIREMENTS

The BCA (cl 2.3) allows unlimited floor areas for a building of one or more storeys, provided it is sprinklered, has vehicular access around the building, and includes an adequate smoke exhaust/venting system. The smoke exhaust aspects of these buildings have been addressed in Chapter 11 and the vehicular access requirements in Chapter 14.

The BCA recognises three levels of fire-resistant construction—Types A, B and C, with Type A being the most fire-resistant and Type C, the least. Type A construction is required if the building has a rise in storey of 4, Type B if it has a rise in storey of 3, and Type C if the building has a rise in storey of one or two.

The current FRL requirements for structural elements are summarised diagrammatically in Figure 12.8 for sprinklered buildings of Class 6. It will be noted that where structural members are required to have an FRL, a value of 180[39] minutes is normally required[40]—but not all members are required to have an FRL. The situations shown include the various "concessions"[41] associated with the provision of sprinklers. If the building has a rise-in-storeys of 4 then Type A construction is required, with the floors, walls, beams and columns all required to have an FRL.

If the building is of Type B construction (rise in storey of 3), the floors are not required to have an FRL. Internal columns, on the other hand, are required to have an FRL. Type B construction is a "lesser" form of construction than Type A and it is clear that the absence of requirements for floors is *deliberate*. This issue is further discussed in Appendix 12.2.

The only elements of a Type C building (rise in storey of 1 or 2) required to have an FRL are loadbearing external walls, external columns and (internal) common and fire walls. Again, the reduced requirements for Type C buildings are clearly *deliberate*.

As noted above, buildings of Types A, B and C construction may be built having unlimited floor area provided such buildings are sprinklered and meet certain other criteria[42]; the type of construction required being a function only of the rise in storey. It is the rise in storey, as opposed to the total number of levels in the building, that matters in determining the type of construction. The implications of this are illustrated in Figure 12.9 where it can be seen that virtually identical buildings can be constructed but will be required to have different types of construction depending on the number of levels *above* ground.

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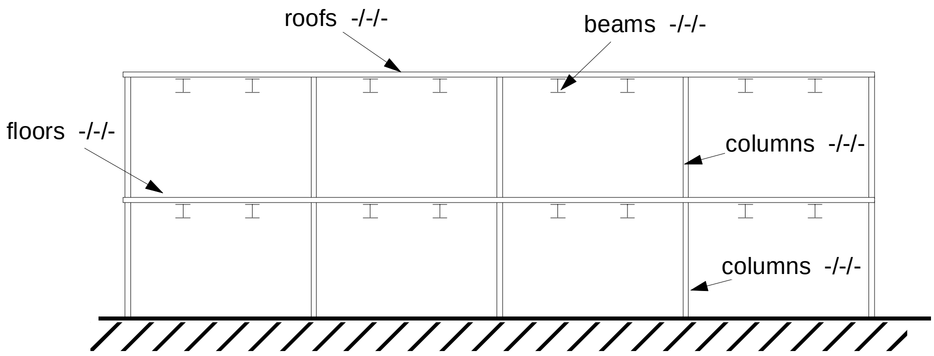
[39] It is recognised that values of FRL are specified in the BCA in terms of the requirements for structural adequacy, insulation and integrity. A single value is given in the text to specify the requirement when a group of elements is mentioned.

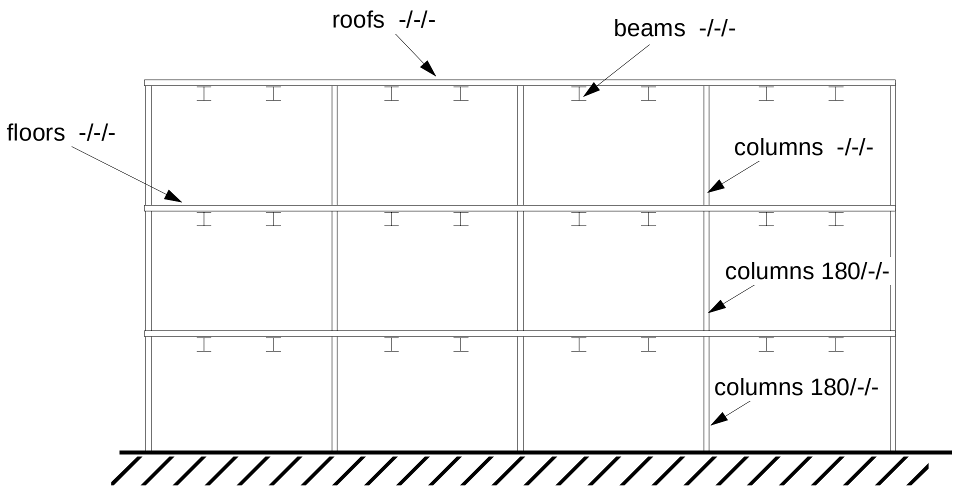
[40] BCA requires lesser values for cinemas and carparks.

[41] The term "concession" is frequently used throughout the BCA and corresponds to a requirement which represents an alternative to the normal regulatory requirement applying to a situation. As these alternative requirements are permitted, it follows that they must be considered to correspond to an equivalent level of safety in certain situations–ie. the situations specified in the "concession". The use of the word "concession" unfortunately implies a lower level of safety. This is not the case.

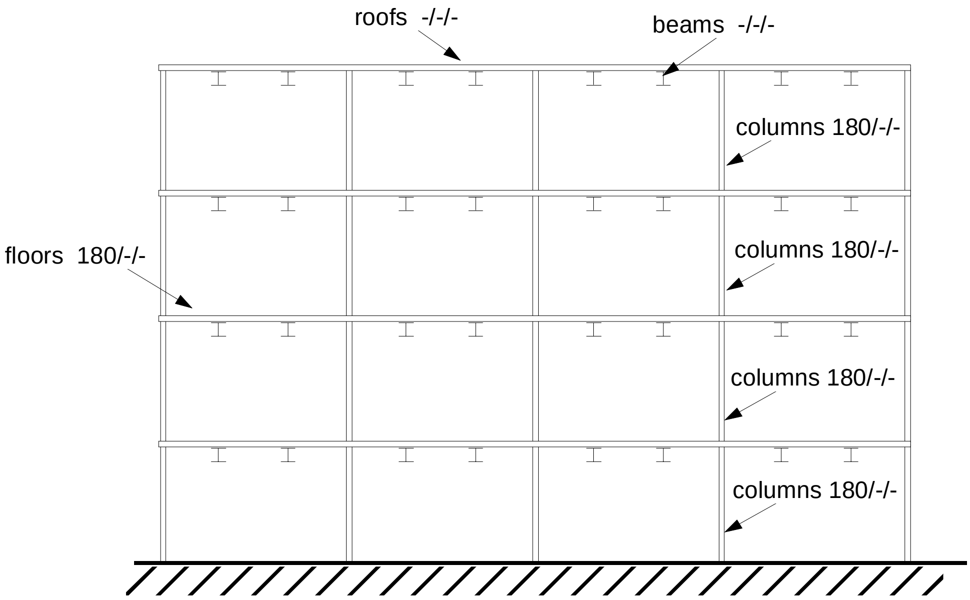
[42] The other criteria are smoke exhaust or venting and vehicular access around the building. For the purpose of the arguments presented in this paper, it is assumed that all buildings, whether Type C or A satisfy the intent of these requirements and therefore their presence is not relevant to the arguments.



(a) rise of storey = 2 (Type C construction)

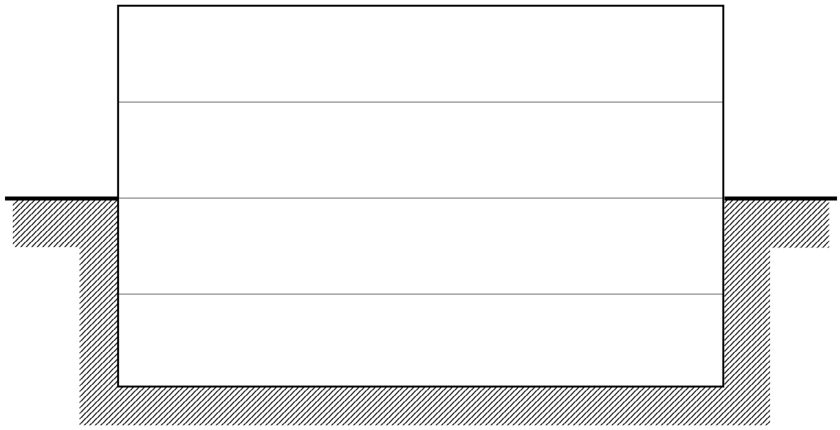


(b) rise of storey = 3 (Type B construction)

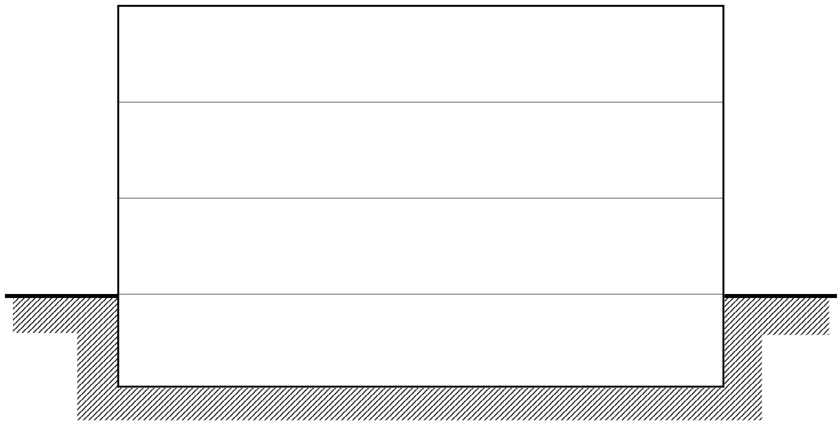


(c) rise of storey = 4 (Type A construction)

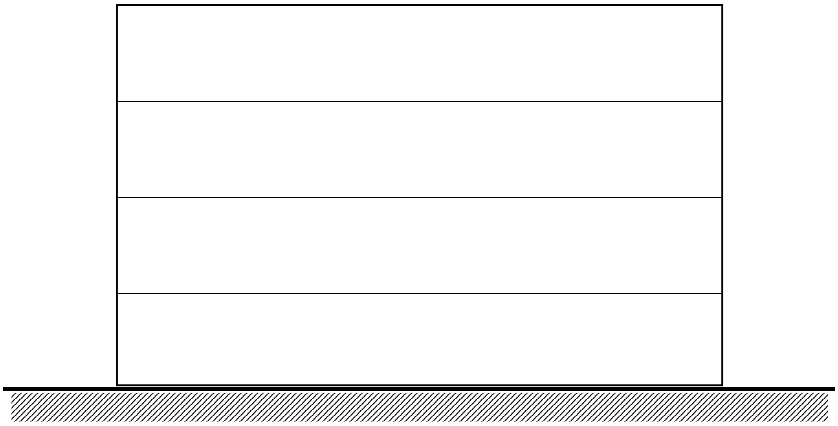
FIGURE 12.8 CURRENT FRL REQUIREMENTS FOR STRUCTURAL ELEMENTS



(a) Type C construction required



(b) Type B construction required



(c) Type A construction required

FIGURE 12.9 TYPE OF CONSTRUCTION REQUIRED

12.4.2 BASIS OF CURRENT REQUIREMENTS

The apparent anomaly[43] between the situations shown in Figures 12.9 (a)–(c) is resolved by the fact that two essentially independent exit paths from the basement levels must be provided. This requirement may have a direct impact on the expected evacuation times for a building and provides a clue to a basis for differentiating between the various types of construction: namely, the ease with which evacuation can be achieved.

This is consistent with the BCA objectives, making it clear that inherent in the current BCA requirements is an acknowledgment that requirements such as FRL's, etc are dependent on the evacuation arrangements and that where *independent* means of evacuation are provided the requirements can be lessened compared with situations where evacuation from a significant number of storeys is through common facilities. This is consistent with the design philosophy presented in Section 12.2.

12.4.2.1 Walls and Floors—Fire Separation Function

Floors and walls are necessary for functional purposes, not only as fire separating elements. As noted in Figure 12.9, floors in buildings of Types B and C construction are not required to have an FRL. However, practical floors (even with a low FRL) will act so as to inhibit the spread of fire vertically to the next level during the stage of fire growth *before* flashover, and for a certain length of time after flashover.

Should a fire continue to grow, without being noticed and extinguished, or without the intervention of sprinklers, then flashover may occur. A flashover fire is much more difficult to contain than a pre-flashover fire—even if the walls and floors have a substantial FRL (as with Type A construction)—and eventually spread is likely to occur. The reason that spread will usually occur is associated with the *only* way that an enclosure can prevent the spread of fire to another part of the building: there must be *no* gaps or openings in its boundaries. However, if this was actually the case, the oxygen within the enclosure (or *fire-resistant compartment*) would usually be consumed prior to flashover, and the fire extinguished. In reality, doorways and windows in walls, and openings in the floors (which provide interconnection between levels eg. escalators and voids), often ensure that a plentiful supply of air is available to the fire and that paths are available for smoke and flame spread.

It is interesting to note, that historically, Type A construction has been assumed to be the standard of construction that can withstand a burnout so that the fire may be *confined* to the compartment of origin. The ability of Type A construction to reliably contain a large flashover fire in any building is questionable due the usual lack of real (complete) compartmentation when the building is in use. It is most certainly *not likely* in shopping centre buildings due to the openings between levels and areas necessary for the free and efficient flow of people and stock.

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[43] A building is always structurally supported from its lowest level.

12.4.2.2 Beams, Floors and Columns—Structural Stability

The BCA functional statements given above require that the structural stability of exit ways be maintained whilst evacuation of the relevant part(s) of the building is taking place. Thus, in the vicinity of a fire, it is important that failure of part of the structure does not endanger people on the fire floor, those directly above it, or interfere with the ability of other occupants to escape.

As will be noted from Figure 12.9, beams in Types B[44] and C construction are not required to have an FRL. It was also observed above that floors in Types B and C construction are not required to have a fire-resistance. However columns in Types A and B construction *are* required to have an FRL, although those in Type C construction are not. A comparison of these *acceptable* requirements with the above mentioned BCA objectives *implies* the following:

i. A large isolated building of Type C construction without specific FRL requirements (rise in storey of up to two) will allow successful evacuation of the occupants.

ii. Eventual failure of part or all of a Type C building (should it occur) will not interfere with the ability of the occupants to evacuate the building. Nor will it present a significant threat to fire fighters.

iii. A large isolated building of Type B construction without specific FRL requirements for the floors (rise in storey of up to three) will allow successful evacuation of the occupants.

iv. Eventual failure of those parts of a floor[45] in a Type B building (including the floor itself and floor beams) not required to have an FRL will not interfere with the ability of the occupants to evacuate the building, nor will it present a significant threat to fire fighters.

In summary, the current regulations assume that floors in buildings with a rise in storey of up to 3 and columns in buildings with a rise in storey of up to 2 do not need to have an FRL to allow safe evacuation of the relevant parts of the building.

In respect of the current BCA requirements, it is implicitly assumed that the occupants will evacuate via exits provided in accordance with Section D of the BCA. The reality of the situation is that buildings designed in accordance with these prescriptive requirements will incorporate exits which are unlikely to be used by the occupants: the occupants will tend to use “familiar” ways of getting away from the fire and to a safer area. The egress design proposals given in Section 11.4 will, in reality, result in *faster* egress times than the current deemed to comply requirements for these buildings due to the fact that familiar exits are designed to facilitate movement and evacuation.

In addition, it may be inferred from the fact that there is no increase in FRL’s required of the structural members in a building of rise in storey of three but with basements (so that the actual structure of the building is four or five or more storeys high) that the purpose of the increased FRL’s in buildings with a rise in storey of four is **not** associated with the actual number of storeys of the

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[44] Beams are only required to have a fire-resistance level in Type B construction subject to the support of another part requirements. These are discussed in Appendix 12.2.

[45] This is the case because the columns are required to have an FRL.

structure— that is, it is not associated with the number of storeys supported by structural elements such as columns and beams.

The addition of an extra floor to a building with a rise in storey of 3 changes the type of construction required from B to A, which means that columns, beams, and floors are required to have an FRL of 180 minutes. *What possible differences are there between these buildings that could justify this abrupt and significant increase in structural requirements*?

> *Building Population is greater?* — This cannot be the reason for differentiating between Types A and B construction, as it is always possible to conceive of buildings having a rise in storey of two or three which have a greater area and therefore greater population than a building with a rise in storey of four.
>
> *Evacuation Time is greater?* — This may be the case but the time for evacuation of part of the building is influenced by the number and width of exits provided, and additional exits or exit widths, etc, can always be provided to ensure that there is no significant increase in exit time.

No additional reasons of any substance have been suggested during protracted enquiries and thus it appears that there is little basis for requiring buildings with a rise in storey of four to be treated significantly differently, with regard to FRL's, to those with a rise in storey of three, where other *effective* means of addressing the effect of the additional storey can easily be envisaged.

Having regard for the BCA functional statements mentioned above it is clearly appropriate that FRL's and other fire safety system requirements depend on:

i. the time required to get to a safe place in the most adverse circumstances (eg people from other areas sharing exits, etc)

ii. perhaps, the number of people depending on the system for passage to a safe place

iii. perhaps, the average and maximum distances to a safe place

It is therefore apparent that, in principle, the requirements should increase from the top of a building to the bottom, although it may be that in some circumstances (such as those as mentioned below) the increase would be minor. It appears from the above analysis of the current requirements of the BCA that the increases in FRL's required by the BCA are primarily associated with increased exit times presumed to occur with increasing numbers of storeys. This is consistent with the findings of Section 12.2

12.5 FIRE RESISTANCE LEVELS

The deliberations of the preceding sections may be summarised as follows:

i. In considering the impact of the building structure (when subject to fire) on the safety of the occupants, the *primary* design fire for these buildings was identified as a *sprinklered* fire (ie. a C2 fire). The findings from the sprinklered tests conducted as part of this project indicate that lightweight members will not be significantly affected by exposure to a sprinklered fire—even assuming that no ceiling is present.

ii. It is recognised that it is also necessary to *consider* the impact of a non-sprinklered fire, to show that even in that situation, successful evacuation is possible. This fire was taken as a C3 fire and found to be *extremely rare*. Such a fire will be accompanied by large quantities of dense smoke and commencement of evacuation will be almost immediate (see discussion in Section 12.2.5.1).

iii. The fire-resistance required for various structural members was recognised as being related to the times required for movement of the occupants to a safe place (mall, street, or adjacent carpark) from a store. A multi-level department store was identified as being the most critical part of the building with the times for movement to a safe place being dependent on the means of egress available at the particular level (ie. stairway within store versus direct horizontal access). Table 12.2 summarises the times for movement to a safe place for various store situations. These times do not apply to the whole shopping centre but to the department store which forms *part* of the centre. The stability of *only part* of the store is under threat and the store *only* forms *part* of the shopping centre.

iv. Floors (including beams) should have sufficient fire-resistance to allow direct movement of the occupants on a level into a mall, carpark, street, or into a stair shaft as the case may be. Based on the data in Table 12.2 it follows that floors only have to survive for less than 5 minutes. It was recognised that practical composite or concrete floors in these buildings will provide sufficient fire resistance to more than easily allow time for movement of occupants to a safe place. It was also noted that these buildings are highly redundant and that failure of part of a floor will not threaten the building.

    The use of independent valving of the floors within the building was seen as beneficial as it would provide a buffer should fire break through the floor slab.

v. As far as columns are concerned, it was recommended in Section 12.2.5.1 that they should have sufficient fire-resistance to allow for the movement of occupants on the level of the fire, and the levels above the fire, to a safe place. The fire resistance required for the columns depends on the level within the building and the means of egress available at each level. Based on the discussion presented in Section 12.2.5.2.2 iv. the columns in the lower levels of a shopping centre should have a fire-resistance level as summarised in Table 12.3.

vi. The shopping centre buildings being considered in this project are large in plan area compared with their height, being the opposite of high-rise buildings which are tall and narrow. As a result there are many columns providing support to the floors. Failure of a column, or even a number of columns will affect only part of the building. The overall stability of the building will not be affected.

vii. A review of case studies found that there were very few cases where the occupants were still in the fire-effected part of the building, when it was subjected to the full severity of a C3 fire. One such building, mentioned in this chapter, incorporated unprotected structural steel members which were exposed to a very severe fire, and were found to offer sufficient fire resistance such that deaths did not result from failure of the structural elements.

viii. *current* regulatory requirements for large isolated buildings strongly imply that it is not necessary to have high levels of fire resistance in these buildings and that these should be based on the times required for evacuation in an extreme situation. There appears to be an unjustifiable increase in the fire resistance requirements for buildings once the rise in storey reaches four compared with those required for buildings of lesser rise in storey.

TABLE 12.3 FIRE-RESISTANCE LEVELS OF COLUMNS IN THE LOWER LEVELS OF A SHOPPING CENTRE

Building Situation	*Level 4*	*Level 3*	*Level 2*	*Level 1*
Direct horizontal access to Safe Place on level 1 only	nil	nil	FRL = 15-30	FRL = 15-30
Direct horizontal access to Safe Place on levels 1 and 2.	nil	nil	nil	nil
Direct horizontal access to Safe Place on levels 1-3.	nil	nil	nil	nil
Direct horizontal access to Safe Place on all levels	nil	nil	nil	nil

The following recommendations are given for members within a sprinklered shopping centre building with a rise in storey of up to four, based on the above considerations:

i. The roof, floor, and columns associated with the upper two storeys of these buildings may be constructed as non-combustible Type C construction;

ii. The floors associated with the other levels may be constructed as non-combustible Type C construction.

iii. Columns which provide support to two or three upper levels should be designed to have a fire resistance of 15-30 minutes and be non-combustible.

iv. Walls separating a carpark from the rest of the shopping centre and associated with fire-isolated exit shafts within major stores should be designed to have a fire resistance of 30 minutes.

The above FRL requirements are principally for the retail parts of the building. Those for cinemas will be less due to the fact that the fire load is lower than for the retail parts of the building. The same requirements can therefore be conservatively adopted for cinemas. In the case of carparks, the requirements specified in BCA 96 [2] are appropriate.

13. BUILDING STRUCTURE—OTHER ISSUES

13.1 INTRODUCTION

Chapter 12 considered the matter of the building structure and what FRL's are appropriate for various structural members. In this chapter, the matter of fire separation of various classes of building is considered, as are door requirements and specific separation issues associated with buildings being classified as atriums.

13.2 SEPARATION BETWEEN VARIOUS CLASSES OF BUILDING

Shopping centres incorporate buildings or parts having different classifications (carpark, retail building, cinema). According to BCA cl C2.8(a), if such buildings of different classifications are adjacent to each other, then either the elements in both buildings must have an FRL which is the highest associated with each classification, or a fire wall must separate the two parts of the buildings.

Are there valid reasons for requiring parts of various classes of building to be separated?

It is clear from BCA cl C2.8(a) that the primary intent of this clause is *not to limit fire spread*[46] but rather to prevent one part of the building (eg. the carpark) being exposed to the fire severity *perceived* to be associated with another part of the building (eg. the retail part). However, the severity of a fire associated with one part of a building is primarily a function of the fire load and conditions in *that* part of the building—not the fire load and conditions in the adjacent part. *There would therefore appear to be no basis for this BCA requirement.*

Fire and smoke separation is required for parts of the building which act as "safe places". However, this is a different matter and is considered in detail in Chapter 11.

13.3 SHUTTERS AND DOORS

In the case of buildings having parts with different rises in storeys, it has sometimes been convenient to "separate" the two parts to allow each to be designed for a different type of construction—rather than the most severe type of construction. An example of this situation is where a 4 storey department store is directly adjacent to a two storey mall. One part of the building was designed as Type A construction, whilst the other, Type C. Separation was achieved by a fire door or shutter, usually activated by smoke detectors.

Shutters and doors, when activated, result in the placement of a blockage across a *normal* pedestrian route within the building (eg. the entrance between a major store and the mall). This action will result in changes in the local appearance of the building (to the occupant) giving rise to associated disorientation, and will interfere with the natural movement and flow of people in an emergency.

It is the opinion of the authors, that the use of such shutters and doors should be avoided at all costs.

[46] This is implied because separation is *not* required if the higher FRL is adopted.

13.4 CEILING SPACE BARRIERS

13.4.1 CEILING BARRIERS BETWEEN GROUPS OF SPECIALTY SHOPS

Unless a specialty shop is a bank or jewellery store, it is unlikely that the walls will extend to the floor above. They will rather terminate at ceiling level. Such construction is permitted by the BCA and is desirable with the view to running services throughout the building. This practice will, however, create a large uninterrupted void within the ceiling space along which fire may rapidly pass from one part of the building to another (see later discussion in Section 14.5.4.2). The presence of *some* barriers within the ceiling space will assist in reducing the rate of spread of fire in the event of a C3 fire. There is therefore merit in providing such barriers at regular intervals to separate groups of specialty shops. It is considered that such barriers should at least be provided approximately every 10th specialty shop or 50m whichever gives the closer spacing.

13.4.2 CEILING BARRIERS AT SPRINKLER ZONE BOUNDARIES

A C3 fire will only develop if the sprinkler system in that area has been isolated for one reason or another. As the C3 fire spreads and approaches an adjacent sprinkler zone, it is possible that the sprinklers within the next zone may be overwhelmed as more and more heads are activated. The progression of the fire via the ceiling space will be one of the major mechanisms of fire spread throughout the building. The provision of a barrier at the junction of the sprinkler zones will reduce the likelihood of the sprinklers within the adjacent (still active) zone being overwhelmed is it will slow the progression of heat into the ceiling space at this junction.

13.4.3 CEILING BARRIER CONSTRUCTION

Ceiling space barriers should 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.

13.5 DOOR CONSTRUCTION

In addition to the shutters and doors discussed in Section 13.3, fire doors are currently provided in the following situations:

i. At the entrance of fire-isolated passages from a mall.

ii. At the entrance to a fire-isolated stair shaft.

The value of fire-isolated passages from a mall has been seriously questioned in this report with an alternative proposal for facilitating movement within the mall and evacuation being presented in Chapter 11. However, assuming that such passages were required, what is an appropriate door construction at the entrance from the mall? The purpose of a door at the entrance from the mall is to prevent smoke and flames entering the passage. However, if the fire is so close that smoke and flames can enter the passage, then the passage cannot be used anyway due to the vicinity and effects of the fire. If the passage is not used, then it does not matter if some smoke gets into the passage or the temperature of the door exceeds the insulation requirements. There appears therefore to be little justification for these doors to have any fire-resistance requirements other than perhaps with respect to integrity. An alternative proposal could be that these doors have an FRL of -/30/-.

What about the doors at the entrance to fire-isolated stairways? In that case, the stairway must be maintained free of smoke at least for a sufficient time for evacuation of the occupants. As these stairways can be within stores where fire may be adjacent to the door on one level but the stairway is needed for evacuation above that level, some significant fire resistance is required. The current door construction is appropriate.

13.6 BOUNDING WALL CONSTRUCTION AS REQUIRED FOR ATRIUMS

It is very difficult to understand the current BCA atrium requirements as they would be applied to a shopping centre building. One such aspect relates to the need for bounding wall construction, which in buildings having a rise in storey of 4, would almost certainly apply to the uppermost level. This requires the positioning of fire-resistant construction (60/60/60 wall) or a drenched glazed wall with a fire barrier above. These walls must be located less than 3.5m from the edge of the walkway.

Presumably the purpose of this construction is to prevent fire spread from fire plumes coming from a lower level or from combustibles located on the atrium floor itself. The presence of flames from below will certainly have a radiant heating effect on combustibles located adjacent to the walkway on a higher level. However, generally glazing will separate the combustibles from the radiant flames, and this, combined with mixing from the air, will cool the smoke and flames. Furthermore, if the radiation is so high, it will activate the sprinkler heads between the shop fronts and the edge of the walkway and this will prevent spread.

It is considered therefore that such bounding construction is not necessary in sprinklered shopping centres with a rise in storey of up to four.

14. FIRE BRIGADE INVOLVEMENT

14.1 INTRODUCTION

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 fire brigade is an important part of the fire safety system, and in relation to the buildings which form the subject of this project, may be considered to have the following specific functions:

a. Act to support the effectiveness of fire safety systems within a building eg. responding to a situation where sprinkler isolation has gone beyond notified isolation period as indicated by monitored valves.

b. 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. participate in 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 or other buildings.

Factors which can have an important influence on the *ability* of the fire brigade to fulfil the above functions include: receiving an alarm; activities and timing including travel and setting-up times; fire brigade facilities; and the size of fire confronted.

The role of the fire brigade is now considered in more detail in relation to the above issues and the range of fires that may be encountered in these buildings.

14.2 ALARMS TO THE FIRE BRIGADE

Alarms to the fire brigade can be from the following sources:

- Occupants who activate a Manual Call Point (MCP) alarm or telephone the fire brigade (via FIP).
- Occupants informing management who activate an MCP or directly ring the fire brigade.
- Smoke detectors and direct line (via Fire Indicator Panel or FIP).
- Sprinklers and direct line (via FIP).
- External observer

Feedback from centre management indicates that MCP's are not used to notify an emergency as it is far more likely that shoppers will draw the attention of staff to the situation who, in turn, will use a telephone. Telephones are much more readily available throughout a centre than MCP's which are activated almost exclusively by vandals.

☛ *One has to question the need for MCP's in public areas (near exits) in sprinklered shopping centre buildings. It is believed that these add little to brigade communication.*

It is interesting to observe that for USA retail buildings, there is generally no direct connection between alarm boxes, smoke detectors, sprinklers, and the fire station. Thus signals from those devices are transmitted to building security who may undertake an investigation before putting the call to the brigade. This is not the case in Australia where signals are transmitted directly to the brigade. Anecdotal evidence suggests that USA practice, in this regard, will result in a higher proportion of larger fires as there will be increased time delays and some fire starts may not even be reported or may be reported too late[47].

As shown elsewhere in this report (see Section 10.2), the presence of occupants within the building is one of the most effective forms of fire detection. Given the evidence of a fire in a specialty shop or within a mall, in addition to early fire fighting, staff will alert building management or perhaps the fire brigade by telephone. Management will probably alert the fire brigade depending on the severity of the situation. In the case of a fire in a major store, the management staff will almost certainly ring the fire brigade, depending on their assessment of the situation. The advantage of alerting the brigade by the telephone is that more specific information can be conveyed as to the location of the fire.

Smoke detectors within the return air ducts may activate earlier than sprinklers, but that is not certain. Thus smoke detectors probably provide a valuable back-up to occupant observation and sprinklers. This would be more the case if smoke detection was provided within the room rather than just within the return air ducting. The most critical time for fire safety however, is when the sprinklers are isolated. *In this case the smoke detection system will only add value if it has* ***not*** *also been isolated*—but this *is* commonly done to avoid "nuisance alarms" during modifications to part of the building. This practice should be avoided if possible. From a property protection viewpoint, the isolation of both sprinklers and detectors in a building during *non-occupied* hours is a dangerous practice.

14.3 ACTIVITIES AND TIMING

It is expected that the fire brigade will react to a call in a timely manner, and that for a significant shopping centre (eg. GLAR—gross lettable area for retail area of 40,000 m^2), the call-out will be attended by more than one appliance[48]—

[47] This was the case with a fire incident at One New York Plaza in which there were 2 deaths and 50 injuries. Despite the fact that the fire was being investigated within the building, the alarm was given from an adjacent building some 8 minutes after the initial alarm. This was also the case with the fire at One Meridian Plaza.

[48] The term "appliance" refers to a fire brigade truck with fire-fighting facilities.

typically three. Each of the units will have a different role and this will reduce the time for certain activities.

Based on advice from the fire brigade [22,23], the following potentially sequential activities and associated times (realistic upper-bound times) have been identified:

i. *Travel to the site.*
   This obviously depends on the distance to the building from the fire station and the density of traffic. The distribution of the time from alarm to firefighter arrival for USA retail buildings [8] is shown in Figure 14.1 and Australian commercial buildings [24] in Figure 14.2. It can be seen that the arrival time rarely exceeds 6 minutes and is likely to be less. Of course, this time is measured from the time of alarm. An average of 5 minutes is adopted.

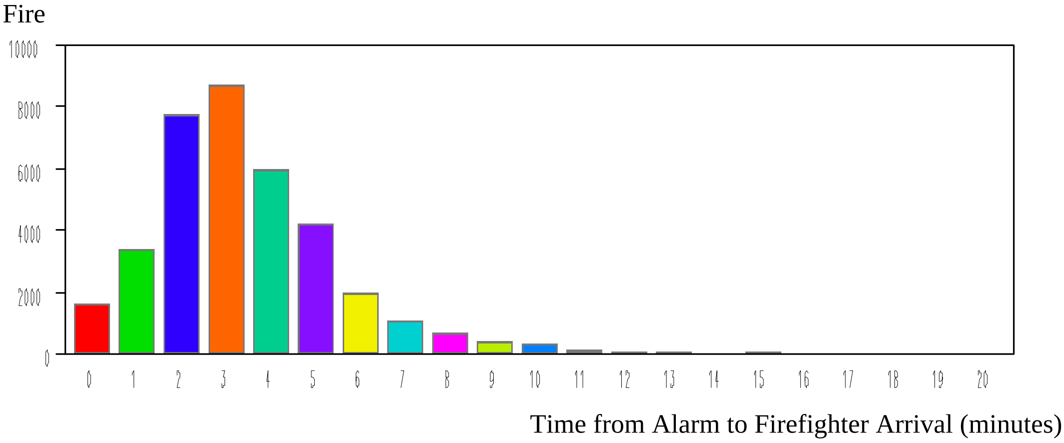


FIGURE 14.1 TIME FROM ALARM TO FIRE BRIGADE ARRIVAL FOR USA RETAIL BUILDINGS

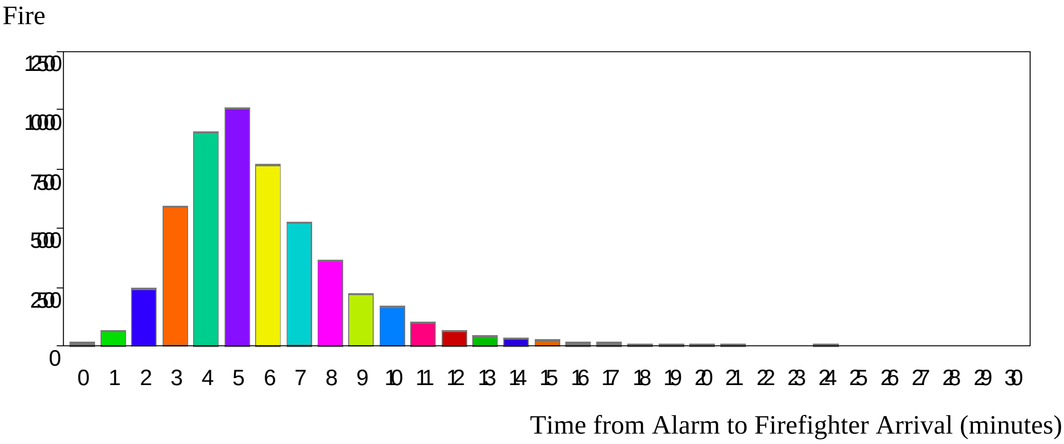


FIGURE 14.2 TIME FROM ALARM TO FIREFIGHTER ARRIVAL FOR AUSTRALIAN COMMERCIAL BUILDINGS

ii. *Travel to the relevant entrance of building.*
This is self explanatory but guidance on this matter can be obtained from centre management if the building is occupied; but if this is not the case, the brigade will go to one of the entrances—presumably the one that is agreed with the building management as the first point of contact (see also v.). The travel time is dependent on the size of the centre and the distance to the preferred entrance. The appliance will travel significantly slower than when travelling to the site. It is considered that an appliance will travel at an average speed of 2.2 m/sec.

One issue that is considered in Appendix 14.1 is whether it is necessary to have continuous vehicular access around the building as required by BCA cl C2.4. It is concluded that this is not necessary in itself, but rather, that adequate vehicular access to nominated major entrances should be provided. As noted in this appendix, the lack of vehicular access around the building can be compensated for by the provision of FIP panels at each of the entrances. Each of these panels would be designed to monitor only the part of the building closest to that entrance. Activation of a detector or sprinkler will result in an alarm to the fire brigade which will indicate the part of the building in which the alarm has occurred. This, in turn, will allow the brigade to make their way to the entrance closest to the potential fire.

iii. *Locate an appliance adjacent to booster connections.*
The boosting of the fire-fighting water supply is important to ensure that there is adequate flow and pressure and is normally undertaken by one of the three appliances. This activity is related to *vi*. and *vii* and can be considered to occur independently of the other activities.

iv. *Dismount vehicle and put on breathing apparatus and prepare.*
This is estimated as being typically between 2—3 minutes.

v. *Enter building to FIP.*
This time can be short (eg. 15—30 secs) but it depends on the location of the FIP in relation to the entrance. It would appear therefore, that it is important to have a FIP or mimic panel close to the “agreed” entrance to minimise any additional delays. There will, of course be interaction between staff and the fire brigade during occupied hours and it is likely that the staff have a better understanding of the location of the fire (and the detector zone) than the fire brigade.

vi. *Remove, connect and charge 65 mm hose from hydrant to appliance.*
See comment under *vii.*

vii. *Remove, connect and charge 65mm hose from appliance to boosters.*
Estimated elapsed time for *vi.* and *vii.* is between 3—4 minutes.

viii. *Gather information from FIP and tactical fire plans*
This is when the Officer-in-Charge (OIC) considers the available information and directs crews. This is estimated as taking up to 2 minutes.

ix. *Travel to set-up area with equipment (hose lines etc)*
This is a function of the distance to the fire area and whether it is on ground level or above. Horizontal travel speed may be assumed to be

1.25 m/s. This time is based on the assumption that the pathway to the fire is relatively clear of smoke and that vision is unimpaired.

x. *Connect and charge hose lines*
This is the activity where water is applied to the fire and is estimated as taking about two minutes. It follows sequentially from *ix*.

xi. *Gather further information and feedback*
This action (by OIC) is aimed at providing additional information in relation to the best strategy for fighting the fire and takes place concurrently with the first application of water.

It is more likely that the fire brigade functions will be successfully achieved if the above times are short. The longer it takes for the fire brigade to arrive and set up, the greater is the likelihood that the fire will be larger—especially if the building is unoccupied or the sprinklers should have operated, but have not. If the building is occupied it is likely that the fire will have been dealt with and an earlier alarm sent to the fire brigade.

In order to give a “feel” for the range of times that may be associated with the fire brigade applying water to a fire, two alternative fire starts are considered in relation to the building introduced in Chapter 9. The first fire is assumed to be in a specialty shop on ground level, and the second, in the identical position but on the uppermost level. The fires are assumed to be located approximately midway between major entrances (exits) to the mall (see Figure 14.3). It is also assumed that the distance of travel from the site entrance to the west entrance of the building is 250 m, and that an appliance stops 15 m from the FIP. The booster connections are assumed to be 150 m from the site entrance. Access to the upper floors is by means of the escalators. No account has been taken of the impact of occupant movement on fire brigade activities and an average travel time to the site has been assumed. The results are summarised in Table 14.1.

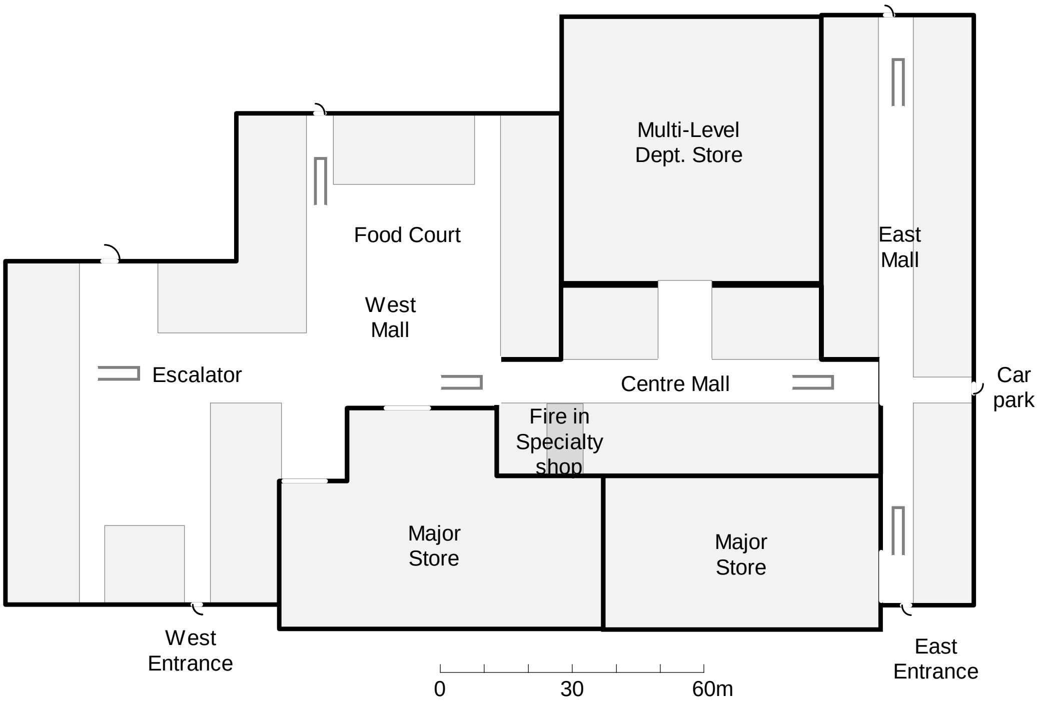


FIGURE 14.3 LOCATION OF FIRE

TABLE 14.1 TIMES TO SUPPLY WATER TO FIRE

Activities	*Crew No.*	*Fire on Ground Level* activity time (secs)	*Fire on Ground Level* elapsed time (secs)	*Fire on Upper Level* activity time (secs)	*Fire on Upper Level* elapsed time (secs)
i.	1,2,3	300	300	300	300
ii	1,2,3	113	413	113	413
iii	3	68	481	68	481
iv.	1,2	149	562	149	562
v.	1,2	15	577	15	577
vi. & vii.	3	200	681	200	681
viii.	1,2,OIC	120	697	120	697
ix.	1,2	125	822	258	955
x.	1,2	116	938	116	1071
xi.	OIC	214	911	409	1106

In summary, it appears that it could take a total of between 15 and 18 minutes from the *time of alarm*, before water is applied to the fire. If building management offer support in terms of direction, it is possible that the above times could be reduced by one or two minutes.

14.4 FIRE BRIGADE FACILITIES

14.4.1 OVERVIEW OF EQUIPMENT USAGE

Table 14.2 gives the frequencies associated with the use of various fire-fighting equipment for the USA.

TABLE 14.2 USA MEANS OF EXTINGUISHMENT

Means of Extinguishment	*%day*	*%night*
self extinguished	18.7	8.5
make shift aids	8.3	3.6
portable extinguishers	24.0	11.6
automatic extinguishing systems	3.5	3.9
hose line from appliance	27.9	33.5
hose line pre-connected to hydrant	12.6	26.6
hose line hand laid from hydrant	3.8	8.7
master stream device	1.2	3.6

The statistics for means of extinguishment for NSW buildings are tabulated in Table 14.3. These figures may be taken as representative of Australian practice.

TABLE 14.3 MEANS OF EXTINGUISHMENT IN NSW

Means of Extinguishment	*%day*	*%night*
self extinguished	12.7	4.3
make shift aids	8.9	4.1
portable extinguishers	30.2	7.7
automatic extinguishing systems	4.9	5.2
hose line from appliance	31.2	57.3
hose line from street hydrant	1.3	2.5
hose line from a hydrant on premises	0.2	-
hose reels in building	2.6	1.2
hose line from hydrant with pump	7	16.9
master stream device	1	0.8

Portable extinguishers are commonly used for putting the fire out and a substantial number of these are the extinguishers from the fire appliance (about two-thirds according to NSW fire brigade statistics) with one third being extinguishers in the building. This does not mean that the occupants had no part to play in controlling the fire, or that building extinguishers were not used in *controlling* the fire, but that the final act of extinguishment was in many cases achieved by the fire brigade using a portable extinguisher.

It appears from a comparison of the above tables, that hose lines *pre-connected* to a hydrant are used in the USA but not in NSW—they are not even listed in Table 14.3. Furthermore, in NSW, there is a very low usage of hose lines (hand laid) from hydrants on the premises compared with the USA (ie. 0.2% cf. 3.6%). In general, it appears that the use of hydrants on the premises of buildings in Australia is extremely rare.

14.4.2 APPLIANCE EQUIPMENT

There are several reasons for the low use of the hydrants *on the premises* of buildings in Australia:

- it is safer and better to move into a fire situation with a pressurised hose as this will offer some immediate protection from the fire should this be required. This can only be achieved by using hose lines from an external hydrant or hose lines and hose reels from an appliance. Otherwise, the building has to be entered before a hose line can be connected to an internal hydrant—thus putting the fire fighter at greater risk.
- hose lines from an appliance offer a higher degree of control of water flow as pressure can be modified by communication with fire fighters at the appliance.

Discussions with the fire brigade indicate, that for buildings of three storeys, fire fighting will most likely be undertaken with hose reels and lines from the appliance. Of course, if there is too far to travel to the fire, then internal hydrants may need to be used (60 m or longer?).

The water that can be delivered by the hose lines and reels from an appliance is dependent on the nozzle pressure, the hose diameter, and the size of the nozzle. Details of the water supply characteristics of various equipment are given in Appendix 14.2. Typically, up to 470 litres per minute could be discharged from a fire hose connected to an appliance. For sustained fire fighting, it will be necessary for the water in the appliance to be replenished from hydrant systems.

14.4.3 EQUIPMENT WITHIN BUILDING

There is some confusion about hose reels within buildings. These are primarily for occupant use and deliver about 40-50 litres per minute assuming a standard 6 mm nozzle. In certain areas of the building they are used for washing down and it is therefore sensible for the hose lines to be connected directly to the domestic water supply.

As far as hydrants within a *sprinklered* building are concerned, the hydrant system must be capable of delivering a total of 1800 litres per minute [13] at the hydrant outlets. This corresponds to three hydrants operating simultaneously with each delivering 600 litres per minute. 65 mm hose lines with 12.5 mm nozzles are normally provided within the building and these are capable of supplying between 150—180 litres per minute with the higher discharge rates being associated with hydrant systems with pumps within the building. A 38 mm fire brigade hose line combined with pressure boosting of the hydrant system can discharge up to 473 litres per minute. This is one of the reasons that the hose lines pre-connected to the building hydrants are not used by the brigade. The other is due to uncertainties associated with such hose lines, especially under a boosted pressure situation.

As the fire hose lines associated with hydrants are rarely (if ever) used by the occupants, and given the above factors, there is little reason for hoses to be provided with hydrants. In fact, these are not required by the BCA but they are normally provided in centres.

☛ *There is little basis for the provision of hose lines pre-connected to hydrants.*

14.5 ROLE WITH RESPECT TO RANGE OF FIRES

14.5.1 INTRODUCTION

From the consideration of fire scenarios in Chapter 8, it was found that the vast majority of fires were confined to the object and area of fire origin. It has been previously suggested that this is primarily through the intervention of the occupants (staff) but that sprinklers also have a significant (but smaller) role. The reality and importance of intervention by the occupants is reinforced by a comparison of the time for fire brigade intervention (15-18 minutes from the *time of alarm*) with the relatively shorter time for some fires to reach flashover (eg. Test 2—see Chapter 6). If occupant intervention did not take place, one would expect to see a great many more fires extend beyond the room of fire origin.

☛ *This discussion reinforces the importance of basic fire fighting training for staff and of the provision of appropriate facilities—portable extinguishers and hose reels.*

The specific role of the fire brigade in relation to each of the classes of fire (see Chapter 8) is now considered.

14.5.2 C1 FIRES

These are fires which are confined to the area of fire origin without the need for sprinkler operation. These are smaller fires for which the fire brigade has the role of final extinguishment to ensure that the fire will not re-ignite.

14.5.3 C2 FIRES

These are sprinklered fires, and in this case, the fire brigade has the role in relation of ensuring that the fire is finally extinguished by means of a hose stream. Isolation of the sprinkler valve should not happen until the fire brigade is at the location of the fire, as re-ignition may occur. As was observed in Chapter 6, re-ignition occurred in Tests 5—9 once the sprinklers were turned off. It will often be necessary to cool the surrounding combustibles with water.

14.5.4 C3 FIRES

It is these fires which present the greatest challenge to the fire brigade. As explained in Chapter 8, it is convenient to divide these fires into those which were confined to the room of origin (C3-1), and those which were not (C3-2). These are now considered in more detail.

14.5.4.1 C3-1 Fires

These are fires where the sprinkler system has not been able to operate but the fire is restricted to the room of origin. These fires will mostly be those where flashover has just occurred, and because of the physical boundaries of the room, the fire has not been able to spread beyond the room. Prompt action by the fire brigade may be needed to contain the fire within the room and finally extinguish it.

14.5.4.2 C3-2 Fires

These fires are more severe than the C3-1 fires as they have extended beyond the room of fire origin. In these fires, the time of arrival of the fire brigade is critical as once the fire exceeds a certain size, it will be difficult for the fire brigade to have a significant impact on the fire. This is due to limitations of water supply compared with the quantity of heat being generated, and quantities of smoke associated with large fires in confined spaces. The various fire scenario groups identified in Chapter 9 are now considered in relation to these fires.

FSG4 — It appears from the discussion presented in Section 8.3.2.4 that between 40—100% of C3-2 fires in major stores must be assumed to have spread throughout the store. An average figure of 70% may be assumed. In the context of a large variety store within a major shopping centre, this type of fire will be so large with such potential for damage, that the fire brigade cannot be expected to do more than *attempt* to prevent further spread. The area already involved will be affectively burnt out.

☛ *This reinforces the need for very high levels of sprinkler effectiveness in major stores during both trading and non-trading hours. Every effort should be made to achieve this.*

FSG7 — C3-2 fires in specialty shop areas are those which have spread into adjacent shops. The following possibilities for spread to neighbouring shops must be considered:

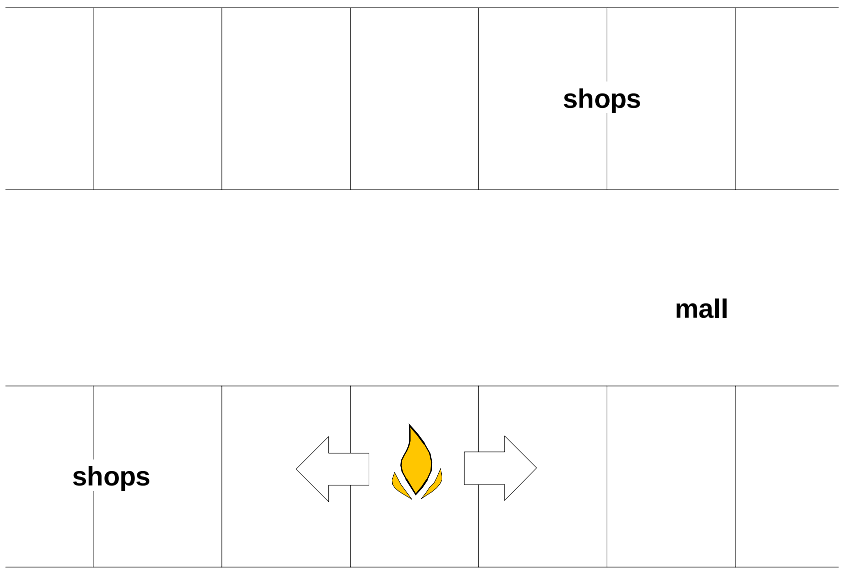
i. *Spread to Adjoining Shops* (Figure 14.4)

Flame spread could be by radiation from the flames at the front of the store such that the glazing in the adjoining shops breaks and spread occurs. Alternatively, once the fire within the specialty store breaks through the ceiling, it can move horizontally within the ceiling space to the adjacent stores. Walls only extend to the floor above where security is a major issue, as is the case with jewellery stores and banks, or where there jeno ceiling. These shops are relatively few. The ceiling cavity jenormally continuous to allow services to be run more easily between shops. The time for the fire to penetrate the ceiling space can be variable, ranging from a few minutes after flashover for ceiling systems incorporating mineral fibre tiles to about 20 minutes for a basic plasterboard system [25]. As far as the performance of the ceilings in the adjacent shops are concerned, this could be expected to take up to 5 minutes from the time at which the fire breaks into the ceiling space. Collapse of the ceilings in the adjacent shops will expose the combustible contents to high levels of radiation with consequent spread. If there is no ceiling within the shop, then the walls will continue to the soffit and this form of fire spread mayenot occur. A few shops (eg. shoe stores) have no ceiling within the storage or private area of the shop (although there jea ceiling throughout the rest of the shop) to allow for greater storage of goods. In such cases the walls doenot extend to the soffit and there jea direct path into the ceiling cavity. Fortunately, this occurrence is relatively rare and it is very unlikely that two such shops will be next to each other.

The roles of the fire brigade in preventing further spread are:

- preventing spread to the adjacent shops— this will require breaking of windows to allow the application of water to the combustibles. Calculations presented in Appendix 14.3 indicate that it will take one hose stream operating close to full capacity to preventing lateral spread. Assuming that spread is taking place in both directions, this will require two hose streams operating at close to full capacity.

- attempting to extinguish the fire within the shop of fire origin—the application of water will absorb energy and reduce the possibility of spread. Extinguishment, however, will be difficult due to the high levels of radiation associated with a flashover fire and distance from which such a fire must be fought.



FIGURES 14.4 FIRE SPREAD TO ADJOINING SHOPS

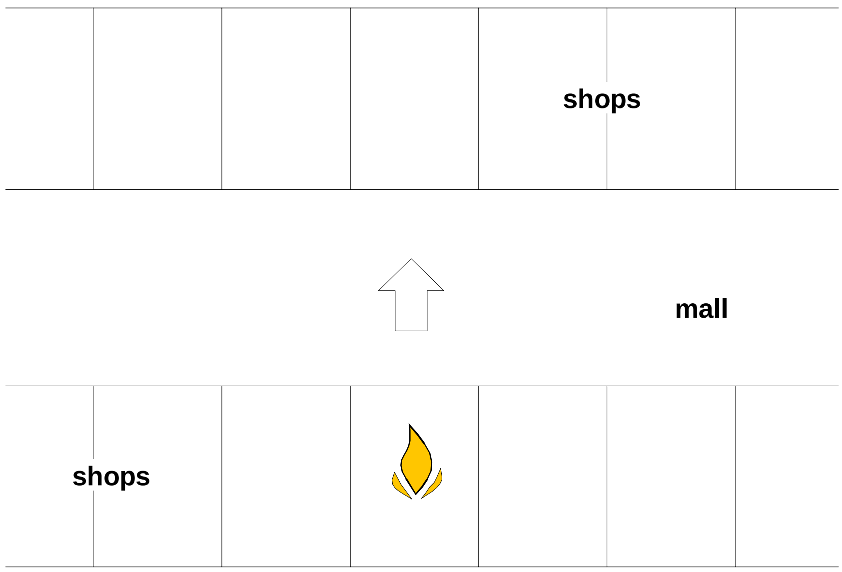


FIGURE 14.5 FIRE SPREAD TO OPPOSITE SHOPS

ii. *Spread to Opposite Shops* (Figure 14.5)

In this case, fire spread is by radiation across the mall. Calculations in Appendix 14.4 indicate that flashover in one specialty shop will probably not result in fire spread across the mall, assuming that the distance between the shop facades is more than 6m. However, flashover in three adjacent shops will almost certainly result in this form of spread.

The role of the fire brigade in this situation is to provide sufficient cooling to the facades of the opposite stores. This requires at least one additional hose stream. If fire spread across the mall has already occurred, additional hose lines may be required.

Without early fire brigade intervention, the fire will continue to spread until it will be very difficult to have much of an impact. It would appear that this point may have been reached when flashover occurs in more than three shops—because at about that time—fire will begin burning on both sides of the mall and radiation and possibly smoke levels in the mall will be high.

But will the fire brigade make it in time?

If the fire within the specialty shop of fire origin is a fast growing fire (which may take only 5 minutes or so to reach flashover), and if there is no occupant interaction, then it is difficult to see how the brigade can arrive in time. On the other hand, if the fire development is delayed in some way by the occupants, or the fire is not a fast growing fire, then it is likely that fire spread can be limited to three shops.

Again, this illustrates the importance of having a very high level of sprinkler effectiveness and the importance of occupant involvement.

F_{SG10} & F_{SG13}—C3-2 fires in structural areas (eg. ceiling cavities) may not be easily accessible and thus may not be contained and extinguished if there are substantial combustibles (construction and other materials) in these areas. This is due to the lack of access into these voids and the fact that such fires may spread at a rapid rate once established. It should be remembered that there are no physical bulkheads in the ceiling spaces of modern shopping centres.

F_{SG16}—These fires are those that break out of the storage rooms into the sales area. As the storage rooms generally have only light construction separating them from the sales areas, it is considered likely that spread will be rapid due to the heat being generated by such fires. Once spread into the sales areas has occurred, the fires will become the same as those described above for sales areas in major stores (F_{SG4}). The same comments apply.

F_{SG19}—These fires are those that break out of the storage rooms within a major store into the sales area. As the storage rooms generally have only light construction separating them from the sales areas, it is considered that spread will be rapid due to the heat from such fires. These fires then become the same as those described above for sales areas in major stores (F_{SG7}). The same comments apply.

F_{SG22} —It is likely that many of these fires will be extinguished by the brigade even though they have spread beyond the room of fire origin, assuming that an alarm is received before the fire reaches flashover. This is due to the fact that most service equipment is in rooms often with substantial walls and little ventilation and the fire load is generally not high. This should generally give sufficient time for brigade arrival before flashover.

F_{SG25} —These fires are extremely rare and appear to be associated with combustibles within fire-isolated stairs and passages. With good centre management these should be non-existent.

F_{SG28} —These are fires in service areas and are assumed to be associated with ducting in buildings. These fires may be assumed to be ultimately similar to those in sales/other areas and the discussions presented for F_{SG4} and F_{SG7} are relevant.

14.6 FIRE BRIGADE INTERVENTION AND THE BUILDING STRUCTURE

Although the impact of the various fire scenarios on the building structure was considered in Chapter 12, it is the purpose of this section to consider the likely impact of the proposed construction (see Sections 12.5, 13.3, 13.4) on various aspects of fire brigade intervention—in particular, *search and rescue* and *fire-fighting* (see Section 14.1 b. iii. - v.) given the presence of a C3 fire. As noted in previous chapters, the occurrence of such a fire will be rare in a soundly managed building—an observation born out by the notable absence, to date, of such fires in these buildings. Nevertheless, it is necessary to consider their likely impact on these fire brigade activities. It is the experience of the authors that considerably greater discretion is exercised by Australian Fire Brigades in assessing the level of danger associated with a situation than in some overseas countries, and that only appropriate action is taken.

In the event of a C3 fire that has got beyond the stage that it can be easily confined and extinguished (eg. a C3 fire that has spread beyond 3 shops), the fire brigade will attempt to make a stand to limit further spread of fire. However, this will be extremely difficult, as indicated in Section 14.5.4.2, not least because the mall will be almost certainly smoke logged due to the fact that the venting/exhaust system will not be able to cope with this size of fire—even though it is recommended in Chapter 11 that the mall be designed for a C3 fire—*but a fire of lesser magnitude*. However, putting aside the issue of smoke logging and whether the brigade can actually find their way into this part of the building, the advanced C3 fire will generate such levels of radiation[49] that fire fighters will not be able to get sufficiently close to be threatened by deforming parts of the building structure—should such deformation occur. As illustrated in Chapter 12, a fire in these buildings will impact the building structure *locally*—not globally: conversely, the smoke from such a fire will affect the building *globally* with

[49] A flame front of 4m x 20m having a temperature of 1000°C will generate a radiation of 7.3kW/m^2 at a distance of 20m. This value can be compared with a value of 6.5 kW/m^2 which human skin can withstand for a period of about 10 seconds.

conditions being worst within levels above the level of fire origin. Thus the greatest threat to the fire fighters in undertaking search and rescue is the smoke generated by such a fire.

Traditionally, the brigade have utilised wall or door construction in combination with the application of water to the unexposed face of such elements of construction to limit the progression of the fire. This allows protection against radiation, containment of the fire, and the application of water to preserve the integrity of the barrier. The application of this concept to these buildings would require the provision of shutters at various locations throughout the building—a practice that was adopted for many older shopping centres. This practice was discussed in Section 13.3 where it was concluded that, although it might offer benefits for fighting the fire, it presents a much greater hazard for the occupants who are trying to escape the effects of the fire. These measures are counter productive.

Are there other measures which could slow the rate of fire spread throughout these buildings and therefore assist the fire brigade in the above roles? The proposal suggested in Section 13.4 is one that appears to have merit as it would slow the rate of spread between groups of shops, and reduce the likelihood of sprinklers in an adjacent, non-isolated zone being overwhelmed. This latter outcome would affectively limit the spread of fire to the boundaries of the zone. Thus the fire brigade could limit the progression of a fire (although not the smoke) to parts of a building by using the sprinkler system to apply water and providing the necessary means to boost the sprinkler supply. It is suggested that this action may be more beneficial than attempting to supply water by hose lines to a large fire within the building.

14.7 SUPPORT FACILITIES

14.7.1 INTERNAL HYDRANTS AND LOCATION

A hydrant system (including booster connection) should be provided for all shopping centre buildings—but under what circumstances should internal hydrants be provided?

The statistical data presented in Section 14.4.1 illustrate that internal hydrants are used extremely rarely and that there are other preferred means of fire extinguishment. An internal hydrant should only be provided when there is no other equivalent means of providing water (via hose lines) to a particular location within the building. Thus an internal hydrant should be provided in parts of buildings where:

i. Water cannot be delivered efficiently by hose lines from an appliance or external hydrant. Efficient delivery of water is dependent on the number of lengths of hose line that must be laid, and the height of the building. It is suggested that the limited number of lengths of hose line that may be laid is two (60m), and the limiting height (beyond which it will be difficult to drag hoses) is two storeys. The length of the hose stream should be taken as 10m in accordance with AS2419.

ii. Water cannot be provided from another internal hydrant.

iii. Buildings are designed to take advantage of in-house fire fighters as explained in Section 14.6.2.

Where an internal hydrant is required, and in order to establish the number of internal hydrants required in part of the building, it should be assumed that two lengths of hose line (60m) can be run from each internal hydrant and that all parts of the buildings must be reached.

14.7.2 Combined Hydrant/Sprinkler Systems

Caution should be exercised with combined systems to ensure that both the sprinklers and fire fighting water in a particular zone are not isolated at the *one* time; as in this case, if a fire occurs within the building during the time that the sprinkler system is isolated, and work is being undertaken on a sprinkler zone such that there are open-ended pipes, then neither the sprinklers nor the hydrants will be of value.

14.7.3 Location of FIP

The FIP, or a mimic panel thereof, should be located near a major entrance to the centre to allow ready access to the brigade, *and at centre management, to ensure prompt response to a fire alarm.*

14.7.4 In-house Fire-fighters

For very large buildings, it may be appropriate—due to the length of time taken for the fire brigade to arrive at the fire location—to have some staff trained in fire fighting beyond the use of hose reels and extinguishers and to provide in-house booster pumps and specialist hose lines that could be fitted to hydrants. These staff will best understand the building layout and be able to source the origin of the fire more rapidly than the fire brigade[50]. This is not to suggest that they replace the function of the brigade, but that their early intervention would be very effective in preventing the C3 fires during the normal operating hours of the building. If this was the case, it could be reasonably assumed that C3-2 fires would be virtually eliminated provided there was a well managed sprinkler system and no combustible materials in the ceiling space.

14.7.5 Fire Control Centres

Provided the FIP's are located as suggested in 14.3 ii and 14.7.3, it is difficult to see any justification for the provision of fire control centres in sprinklered shopping centres. With modern communication, emergency evacuation and fire fighting do not need to be directed from a room within the building that could be located at very great distance from where the fire or emergency is located.

[50] This concept is similar to that of a "works" brigades at plants and mining sites where response and knowledge of the plant is critical.

15. PROTECTION OF PROPERTY

The issue of property protection is of importance to both owners and operators of shopping centres. Throughout this report comments have been made regarding property protection, and it is the intent of this chapter to summarise the key points.

From overseas statistics [16] it is known that the costs associated with a fire are divided as follows:

Building contents	Consequential Losses	Building Structure
43%	36%	21%

Consequential losses include those associated with the loss of business. It can be seen that 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 can never be always achieved in these buildings but routine surveillance and associated electrical maintenance as described in Section 8.4 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 the occupants. In chapter 8 it was found that the majority of fire starts (70%) occur during the hours that the building is occupied by shoppers due to the demand for heating and electricity and the activities of the occupants. During occupied hours it is very likely that fires will be confined to the object or area of origin prior to the sprinklers activating. This is less so during the night when the building is occupied by a skeletal staff only, but even then, it appears that many of these fire will not go beyond the area of fire origin.

A soundly managed sprinkler system is the remaining way of restricting the fire to the area of fire origin—although activation of sprinkler heads may result in substantial water damage. Nevertheless, this damage will be substantially less than that experienced if the sprinklers are not present or functioning. The statistics presented in [8] indicate the average damage associated with fires in sprinklered buildings (which are normally the larger buildings) is less than one third of the average damage cost associated with fires in non-sprinklered buildings. Data presented in [16] suggests that the benefits of sprinklers may be considerably higher than suggested by the above statistic. It follows that the sprinklers should be soundly managed as described in Chapter 7 and that any attempts to increase their effectiveness from a design perspective should be encouraged. It is generally not wise from a property protection viewpoint to isolate sprinklers during the night as there is a greater likelihood that a fire start will not be detected by the occupants.

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

16. CONCLUSIONS AND RECOMMENDATIONS

16.1 INTRODUCTION

Modern shopping centre building are large in plan compared with their height, and in this regard, that they are the opposite of high-rise buildings. However, building regulations have been developed with the latter buildings in mind. It is therefore not surprising that current BCA requirements may not be appropriate for these buildings. Shopping centre buildings, because of their volume and interconnected levels, offer efficient and natural egress paths for the occupants to move away from the fire-effected part of the building. Their large plan area means that they are highly redundant from the point of view of the effect of a fire on the structure and that overall building failure is almost inconceivable given any *credible* fire.

The objective of the research project reported herein is to review the requirements in the BCA which apply to low-rise sprinklered shopping centres, and to propose a more rationally-based set of requirements which will 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. The conclusions and recommendations given in this section apply directly to low-rise *sprinklered* shopping centre buildings having a rise in storey of up to four.

This report has summarised the findings from the various parts of the project, many of which were described in detail in other reports. However, in this report, the authors have attempted to assess the available data and propose a rational basis for the design of these buildings.

In [6] a series of key issues were raised in relation to the BCA requirements for these buildings. These key issues have been raised again in this report. Major conclusions reached throughout the report are summarised in Section 16.2 and a brief response to the key issues by means of specific reference to the relevant part of the main text is given in Section 16.3.

16.2 SUMMARY OF MAIN CONCLUSIONS

The following is a summary of some of the main conclusions reached in this report:

- Statistical data from the USA and the more limited data from Australia show that shopping centre buildings do *not* present a significant risk to life from fire. The average fatality rate for such buildings in the USA indicates a death rate of 0.74 per 1000 fires reported to the fire brigade. A high proportion of fatalities in these buildings are associated with those who are asleep or intimately involved with ignition and flammable liquids. The above death rate does not take into account the *beneficial effects of sprinklers* and is exactly *one tenth* of that associated with *residential buildings* in the USA. If the occupants in a shopping centre building are awake and aware, it is very unlikely that they will perish in a fire. *From the USA data, sprinklers appear to reduce the death rate by about a factor of three.*

- There is a general trend, as might be expected, for the numbers of civilian deaths and injuries to increase with size of the fire. If by some means all fires could be confined to the object first ignited, then the civilian fatality rate would probably fall by a factor of nine.
- More fires occur during normal operating hours due to the greater demand on electricity, heating, cooking and the use of appliances. Nevertheless the *majority* of these fires are detected by the occupants and extinguished before they extend beyond the area of fire origin. These are small fires (termed C1 fires) to which the fire brigade may or may not be called. The occupants therefore have a major impact on controlling fires in these buildings.
- Sprinklers also have a very significant impact on whether fires are confined to the area of fire origin.
- The effectiveness of a sprinkler system in these buildings is most dependent on how it is managed. The system must be *soundly managed* in accordance with the principles given in Section 7.3 in order to minimise the times for which the sprinkler zones are isolated. If this is the case, and the sprinklers are designed to be commensurate with the hazard, then the average effectiveness can be taken as 98.5% for sprinkler zones associated with specialty shops and 99.5% for sprinkler zones associated with major stores. This compares with an average effectiveness of 86% associated with retail buildings in the USA. Thus buildings in Australia with well managed sprinkler systems would be expected to offer a higher level of fire safety.
- Sprinklers associated with major stores should be separately valved to those associated with specialty shop areas and each valve should relate to only one level in the building. Any reduction in sprinkler zone size for specialty shop areas is to be encouraged provided that any subsidiary valves are monitored and positioned in appropriate locations.
- The presence of a soundly managed sprinkler system means that the probability of having a fire which goes beyond the area of fire origin and is not controlled by the sprinklers (described as a C3 fire—see Chapter 8) is *extremely* small. In considering the impact of fire in these buildings it was concluded that the *primary* design fires for these buildings should be *sprinklered* fires (ie. C2 fires). Specific recommendations are given in this regard, and a particular type of C2 fire denoted as a C2-4 fire was identified as being a possibility, depending on the position of sprinkler heads in relation to combustibles in high racking. The occurrence of such a fire will be fairly unlikely, but not as unlikely as a C3 fire. It is also necessary to *consider* the impact of a *credible* C3 fire, to ensure that even in that situation, successful evacuation is possible. However, the margin of safety adopted when considering the C3 fire should be considerably lower than when designing the building for a C2 fire, due to the fact that the latter fire is more likely than the former.

- Studies of occupant behaviour and movement suggest that fire-emergency “passages”, as commonly provided for emergency egress from the mall, are unlikely to be used by the occupants (including staff) in the event of a fire. Thus shopping centres which are designed around this concept—which is encouraged by current regulations—do not provide a sufficient means of egress in the event of a fire. A better and alternative concept is to utilise the normal exit/entrance routes as evacuation paths and to design the building accordingly.
- In the event of a fire in a shop or store, people will move from the fire-effected area into the mall and then away from the fire. It is most reasonable therefore to design the mall as a “safe place”—a *natural haven* for people seeking to move away from the fire. Specific design recommendations are given in Chapter 11 and include the requirement for the mall to have “infinite tenability” in the case of a C2 fire, and sufficient normal exit paths and smoke control to allow evacuation of any level within the mall given a C3 fire. Normal exit paths include open stairs and escalators within the mall to other levels and direct horizontal access paths to safe places such as adjacent carparks and street level outside.
- As far as smoke management of major stores is concerned it is recommended that the exits comply with the current deemed to satisfy requirements of the BCA with the exception that the entrance to the mall also be considered as an exit. Major stores should be designed to allow evacuation in the event of a C3 fire.
- For specialty shops, the maximum distance of travel to an exit (ie. into a safe place or to an open space) should not exceed 20 m.
- The presence of an Evacuation Management Plan and associated training is of fundamental importance. The training of wardens should be sufficient to allow them to have a positive impact on any evacuation.
- The building structure must have structural adequacy sufficient to ensure that, when subject to a fire, it does not interfere with the ability of the occupants to move away from the fire. The current requirements for shopping centre buildings having a rise in storey of 4 are based on those for high-rise buildings which are tall with respect to their height, and which have very limited means for egress. Shopping centre buildings, as noted previously, are wide with respect to their height, with many routes for evacuation and much structural redundancy. These buildings should not be designed as high-rise construction.
- The primary design fire for considering the impact of the building structure (when subject to fire) on the occupants, is a sprinklered fire (C2 fire). However, it is also necessary to *consider* the impact of a credible C3 fire, to show that even in that situation, successful evacuation is possible. The findings from the sprinklered tests, conducted as part of this project, indicate that lightweight members will *not* be significantly affected by exposure to a sprinklered fire—even if no ceiling is present. That is, sprinklered fires have negligible effect on the building structure.

- The building structure when subject to a C3 fire should have sufficient fire resistance to allow the movement of the occupants to a safe place. The fire resistance required should therefore relate directly to the time it takes for the occupants to move to a safe place. The areas within a shopping centre capable of having a significant C3 fire are the specialty and major stores. The widespread use of combustible construction materials within large shopping centres has been rare, and as a result, it has not been possible to fully evaluate the impact of such materials on fire safety within these buildings. The mall areas, which provide the primary means of escape for occupants, must be constructed in such a way as to minimise the risk of spread of flame in the event of a C3 fire. To achieve this, it is recommended that ceilings in malls and walkways are group D materials (eg. masonry; gypsum plaster, paper faced and painted; some fire-retarded timbers and timber products) as defined by FCRC Project 2.
- Within the established limits of the shopping centres studied, the most critical part of these buildings was identified as a department store with a rise in storey of 4. This case was studied to determine the effect of egress path—ie. fire-isolated stairs or direct horizontal access to a safe place outside the department store—on the time for movement to a safe place and therefore the associated requirements for floors and columns at various levels within the building. The following conclusions were reached for members within a sprinklered shopping centre building with a rise in storey of up to four:
    - columns associated with the upper two storeys of these buildings may be constructed with 15 minutes fire resistance
    - columns which provide support to two or three upper levels should be designed to have a fire-resistance level of 30 minutes
    - floors should be constructed with 15 minutes fire resistance
    - internal, non-loadbearing walls between occupancies may be of protected lightweight construction, incorporating combustible or non-combustible framing: linings to these walls must comply with clause C1.10 of the BCA
    - walls separating a carpark from the rest of the shopping centre, and associated with fire-isolated exit shafts within major stores, should be designed to have a fire-resistance level of 30 minutes
    - materials of construction should comply with the general requirements of BCA clause C1.10: any restrictions which currently exist on the use of materials for ceilings and linings remain unchanged except that ceilings in malls (and walkways) should be non-combustible for the reasons noted above.

- The use of fire shutters which close off parts of the building to restrict compartment sizes should be avoided across circulation routes.
- As far as fire fighting is concerned, the intervention of the occupants is important. This combined with a soundly managed sprinkler system will most affectively allow the fire brigade to extinguish fires in these buildings. This reinforces the need for basic fire fighting training for staff and of the provision of appropriate facilities—portable extinguishers and hose reels. Extinguishers are best provided in specialty shops and major stores. For a very large building, it may be appropriate—due to the length of time taken for the fire brigade to arrive at the fire location—to have some staff trained in fire fighting beyond the use of hose reels and extinguishers and to provide in-house booster pumps and specialist hose lines that could be fitted to hydrants. These staff will best understand the building layout and be able to source the origin of the fire more rapidly than the fire brigade[51]. This is not to suggest that they replace the function of the brigade, but that their early intervention would be effective in virtually eliminating C3 fires (which are very rare anyway) during the normal operating hours of the building.
- As far as fire brigade access to the site is concerned, it is important that the fire brigade has access to major entrances of the building, but the provision of continuous vehicular access as required by BCA cl C2.4 is not necessary provided the brigade can be directed to the appropriate entrance.
- High levels of fire safety will only be achieved in these buildings provided all fire-safety systems (particularly sprinkler) are properly commissioned and managed throughout the life of the building. Specific management plans should be developed, implemented, and audited on a regular basis, to maximise the effectiveness of these systems.

16.3 RESPONSE TO KEY ISSUES

As noted in Section 16.1 various issues have been raised throughout this report. In every case an attempt has been made to address the particular issue, but in most cases, the response cannot be captured by a sentence. In such situations, specific reference is made to the relevant part of the report where the issue is addressed and specific recommendations given.

51 This concept is similar to that of a “works” brigades at plants and mining sites where response and knowledge of the plant is critical.

16.3.1 Fire Resistance and Compartmentation

key issues	recommendations
♦ What separation should be provided between different classes of building within the one building structure?	• Section 13.2
♦ If separation is required, what is an appropriate door construction?	• Section 13.5
♦ What fire-resistance levels are required for columns, beams, floors and walls?	• Section 12.5

16.3.2 Evacuation

key issues	recommendations
♦ What exit spacing and width requirements should apply for these buildings?	• Section 11.4.2
♦ What areas within a shopping centre should be isolated with walls to facilitate safe egress and what is an appropriate door construction at openings?	• Section 11.4.2.2
♦ Should an EWIS be required?	• Parts of EWIS are helpful eg. PA system but evacuation will be facilitated by staff being present.
♦ If an EWIS is required, what should be its characteristics—WIP's, type of evacuation signals, initiation of evacuation signal ?	• WIP phones are not necessary in these buildings as radio communication is now used and is more flexible. Shopping centres are not high rise buildings.

16.3.3 Emergency Vehicle Access

key issues	recommendations
♦ What access is required for fire-fighting and other emergency vehicles?	• Section 14.3 ii
♦ Are the vehicular access requirements of C2.4(b) necessary?	• Section 14.3 ii

16.3.4 Fire fighting Provisions

key issues	recommendations
♦ Are hydrants within the building required for fire fighting?	• Section 14.7.1
♦ If this is the case, where should these hydrants be best located?	• Section 14.4
♦ Under what circumstances are fire control centres really necessary?	• Section 14.7.5

16.3.5 Smoke Control

key issues	recommendations
♦ What is the reliability of smoke control systems—do they work?	• Section 11.3.3
♦ What are appropriate design fires for smoke control systems?	• Section 11.5
♦ What characteristics are required of smoke exhaust/venting systems for life safety?	• Chapter 11 generally
♦ What characteristics are required of smoke exhaust/venting systems for property protection and fire fighting?	• Considered to be addressed through providing sufficient means for evacuation of the occupants.

16.3.6 Atrium Requirements

key issues	recommendations
♦ Is boundary wall construction according to BCA cl G3.3 required for these buildings?	• Section 13.6
♦ Under what circumstances will sprinklering of an atrium roof be effective?	• Also relevant for the roof of a mall - See Section 7.4
♦ Under what circumstances are "break glass" alarms required?	• These are not required in public places - see Section 14.2
♦ Under what circumstances is a standby power supply required in these buildings?	• Not considered but difficult to see why needed as these buildings should not be considered as atriums.

16.3.7 Sprinklers

key issues	recommendations
♦ How reliable are sprinklers in these buildings and how can this be maintained/improved?	• Chapter 7
♦ What Grade of water supply is required in buildings having a height of less than 25 m?	• Chapter 7 but Grade II supply recommended for larger buildings
♦ Under what circumstances will sprinklering of a mall roof be effective?	• Section 7.4

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APPENDIX 7.1

ANALYSIS OF FIRE INCIDENT SPRINKLER DATA

APPENDIX 7.1 ANALYSIS OF FIRE INCIDENT SPRINKLER DATA

From the USA fire statistics [8] there were 10,231 fires in sprinklered retail buildings. The data associated with sprinkler performance are summarised in Table A7.1 in order to obtain an estimate of the average effectiveness of sprinklers associated with these buildings.

TABLE A7.1 USA STATISTICAL DATA ON SPRINKLER PERFORMANCE

Sprinkler Operation?	*Extent of Flame Damage*	*No. of Fires*
operated	1	1065
"	2	1421
"	3	453
"	4	46
"	5	77
"	6	177
"	7	30
did not operate but should have	1	222
" "	2	112
" "	3	32
" "	4	8
" "	5	7
" "	6	46
" "	7	10
fire considered too small to operate sprinklers	1	4820
" "	2	1366
" "	3	169
" "	4	32
" "	5	31
" "	6	87
" "	7	20

It will be noted that the extent of flame damage is expressed in relation to:

- the object/area (1 and 2);
- the room (3)
- the fire-rated compartment (4)
- the storey (5)
- the building structure (6)
- beyond the structure (7)

The size of the fire would be expected to increase with the extent of flame damage category. In the case of sprinklered buildings it seems reasonable to assume that if the sprinklers have activated, the fire would be confined to the room of fire origin—unless the system was overrun. As will be noted below, there are some apparent anomalies in the data and adjustments are made for these (see ii. and iii.).

i. Where sprinklers are present in buildings they only operated in $\frac{3269 \times 100}{10231} = 32\%$ of situations. This is principally due to the prompt action of the occupants or the fire being self extinguished.

ii. In the "too small to operate" category there were 170 fires where the flame damage was entered as 4 or greater. This indicates that these latter fires were small and caused some damage outside the room or fire origin, or started in a space that could not be classified as a room. Thus it can be inferred, that on the average for every 1000 fires that are restricted to the room of fire origin, there will be 27 fires which are *recorded* as having an flame spread beyond the room but which are, in reality, small fires and should have been added to the fires restricted to the area of fire origin group.

iii. No reasons are given in the USA data regarding the reasons for non-performance of the sprinkler system and there is no record of the number of sprinkler heads activated. However, it is interesting to note that there were 334 fires in the "should have operated but didn't" category which did not extend beyond the *area* of fire origin. It is difficult to believe that all of these fires should have operated the sprinkler system given the large number of fires of this size which were judged as being too small to activate the system - and given the fact that there is a tendency to *underestimate*[52] the size of fire required to activate sprinkler heads.

Based on the fact that 6186 fires were confined to the area of origin and were judged as too small to activate the sprinklers and that 2486 fires were also confined to the area of origin but activated the sprinklers, it estimated that $334 - \frac{334 \times 2486}{6186} = 200$ of these fires were likely to have activated the sprinklers but did not. There were a further 103 fires with flame spread from 4 - 6 where the sprinklers should have operated but did not. This number can be further reduced according to ii. above to give: $103 - \frac{27 \times 334}{1000} = 95$.

iv. From the figures presented in iv. it can be inferred that the sprinklers should have operated, but did not, in 200 + 95 = 295 fires.

This suggests that the *reliability* of the sprinklers may be taken as:

$$= 1 - \frac{295}{3269 + 295} = 0.92$$

v. Considering the situations where the sprinklers operated, it will be noted that there were 330 cases out of 3269 where the extent of flame spread was beyond the room of fire origin. This number

52 This judgment is based on observations of the reactions of fire-fighters to a range of fires where sprinklers were activated. In almost all cases, it is considered that the sprinklers will activate earlier.

can be reduced due to the matter mentioned in ii. and gives $330-\dfrac{3269\times 27}{1000}=241$ fires which may be considered to have given rise to the sprinkler system being overrun. This gives an *efficacy* value of $1-\dfrac{241}{3269}=0.93$.

It follows that the effectiveness may be taken as $0.93\times 0.92=0.86$

In New South Wales there were 3765 reported fires in retail buildings over the period 1987 - 1995. It is known that 419 of these fires were in buildings where sprinklers were present. Again, in most of these cases, the fire was extinguished before the sprinklers operated. Table A7.2 summarises the sprinkler performance.

TABLE A7.2 NSW STATISTICAL DATA ON SPRINKLER PERFORMANCE

Sprinkler Operation?	*No. of Fires*
sprinklers but perf not indicated	7
fire too small	182
operated but perf not reported	2
extinguished fire	146
prevented spread	71
operated but did not prevent spread	6
should have operated but did not	5

It is of interest to tabulate the number of fires associated with given numbers of activated heads versus the extent of flame damage. This is presented in Table A7.3.

TABLE A7.3 NSW STATISTICAL DATA ON NUMBER OF HEADS ACTIVATED

Extent of	*No. of fires activating the following number of heads*								
Flame Damage	0	1	2	3	4	5	6	7	>7
1 & 2	182	134	22	11	1	1	2	1	2*
3	9	18	4	1					
4		1					1		
5	2	1		1					
6	4	4	1	3					
7	1		1						
not recorded	4	6	1						

*only one fire activated more than 8 heads.

The above data, which admittedly is limited, reveals the following:

i. According to Table A7.2 the failure rate of the sprinklers is $\dfrac{5\times 100}{148+71+6+5}=2.2\%$ and the sprinklers were judged to not *control* the fire in a further $\dfrac{6\times 100}{148+71+6+5}=2.6\%$ of fires. The latter judgment is somewhat subjective and would be expected to result in large numbers of sprinkler heads being activated. In the case of a shopping centre building, this would be expected to correspond to more than 8 heads being activated. Table A7.3

shows there is only one case where this occurred. The only other explanation is that some of these buildings were partially sprinklered such that the fire spread into areas where sprinklers were not located. It is known that many older sprinklered buildings were partially protected. However, taking the above numbers at their face value gives an average *reliability* of 0.98 and an *efficacy* of 0.975. The values give an average *effectiveness* of $0.978 \times 0.974 = 0.95$. It is expected that with an absence of partial sprinklering, better management of the sprinkler system, and stricter control of the location of sprinklers in relation to some storage situations, this value of effectiveness will be able to be substantially improved.

ii. Table 7.3 shows that $1 - \frac{8 \times 100}{217} = 96.3\%$ of fires, where sprinklers operated, had 3 heads or less activated.

APPENDIX 7.2

SPRINKLER FAULT TREE ANALYSIS

APPENDIX 7.2 SPRINKLER FAULT TREE ANALYSIS

The purpose of this appendix is to more fully investigate the reliability of sprinklers in modern shopping centre buildings and to investigate the contribution of various factors to sprinkler uncertainties. Since the factors considered below are independent, the probability of occurrence of two or more of these factors simultaneously is the product of the corresponding probabilities. The resultant probability is dominated by the lowest probability (for factor vi.) as this is significantly less than the probabilities associated with the other factors.

The following are possible factors why there may not be water at the sprinkler head:

(i) No water to the building due to mains breakdown or total isolation of the water supply.

Failure of the water supply in a major shopping centre is undesirable from a functional point of view and for that reason, the water supply to these buildings is generally extremely reliable. Water is sourced from larger mains due to the quantity of water required and this means that mains breakdown frequency is less likely that for smaller pipes. Grades I or II water supplies are normally provided for major centres and these may be assumed to have a failure rate of 0.001 (or a reliability of 99.9%). A Grade III system may be significantly less. The above number corresponds to about 9 hours per year where water is not available due to mains breakdown. From discussions with shopping centre management this would appear to be a conservative estimate.

(ii) Water is supplied to the building but there is inadequate pressure due to failure of pumps, if any.

The requirements for dual pumps with Grades I and II systems makes the likelihood of this occurrence fairly small. Indicative failure probabilities obtained from expert opinion are

- diesel & diesel (no systematic maintenance)< 0.02 per year
- diesel & diesel (maintained weekly)< 0.0002 per year
- diesel & electric (no systematic maintenance)<0.0005 per year
- diesel & electric (maintained weekly)<0.00005 per year

The provision of an external booster connection for the fire brigade provides the necessary back-up should the pumps associated with the sprinkler system fail.

(iii) Blockage within pipe work such that a sprinkler branch is isolated

Provided the system is adequately commissioned and subsequent tenancy work undertaken by qualified and competent fitters it is considered that the likelihood of this occurrence is extremely small.

(iv) Sprinkler head activates but debris within the pipe work leads to blocking of a head.

This is possible but very unlikely - especially if the system has been properly commissioned. In any case, the chance of two adjacent heads being blocked in this manner, will be close to zero.

(v) The system has been unintentionally or intentionally isolated at the sprinkler valve

With required monitoring of all valves back to the fire station the likelihood of this occurrence is extremely small. In any case, it is simply a matter of turning the valve back on once the fire has been discovered.

(vi) Part or all of the sprinkler system is isolated for tenancy upgrades

It is this last factor that has the biggest influence on sprinkler reliability. Modifications of parts of shopping centre buildings are undertaken almost continuously and this requires isolation of sprinkler zones within the building on a regular basis. This matter was studied in detail in [5] where information is given on the times and duration of sprinkler zone isolation. Information was obtained on sprinkler isolation frequencies for three major shopping centres, two of which had undergone considerable changes over the period of time for which data had been obtained. Additional information was obtained from centre management in other centres on the estimated average number of times that specialty shop areas and major stores were isolated. This information is used below to assess the average percentage of time during a year that sprinklers are active.

Modifications to specialty shops generally take place on a much more frequent basis than modifications to major or department stores and it is therefore appropriate to consider each of these separately.

Specialty Shops

Specialty shops are usually modified to allow occupation by a new tenant—and in that case—there are few combustibles within the shop. However, the neighbouring shops are also connected to the isolated sprinkler zone, and should a fire occur in these shops, water will not be available.

According to the isolation data obtained in [5], for the centre experiencing the greatest frequency of sprinkler isolation, a total of 500 hours of isolation were experienced over 20 months and 6 sprinkler zones. Thus, the sprinkler zones were isolated for a total of $\frac{500 \times 12}{20 \times 365 \times 12 \times 6} = 0.011$ of the time during occupied hours. This estimate is conservative (ie high) as it has been assumed that *all* isolations occurred within the normal occupied hours.

Another approach to estimating the above isolation time is using centre management data from other centres. It was estimated that up to 13% of shops are isolated per year. Assuming 30 shops per valve (there are usually more) and that it requires 2 days of work for each shop (one day removal and one day refit) then the proportion of time that the sprinkler zones are isolated is:

$$\frac{13 \times 30 \times 2 \times 8}{100 \times 12 \times 365} = 0.014$$

Thus it is reasonable to consider that the sprinkler zones associated with specialty shops are isolated for 0.015 of the time (ie. are active for 98.5% of the time)—assuming that the sprinkler system is soundly managed and that extended isolations are not permitted.

Major Stores

In the case of a major store, isolation of the sprinklers is sometimes required when the store is being modified for a new tenant or where the whole floor is to be refurbished at the one time; in that case, there will be few combustibles within the store. As the isolated sprinkler valve does not control sprinklers in other parts of the building (*provided major stores are valved separately to specialty shop areas and each level has a separate valve*) the fire-safety of other parts of the building will not be compromised.

The other situation that occurs is when a department or major store is being progressively modified or modified only slightly, and trading activities and combustibles are located on that floor. This is potentially the most serious situation but fortunately occurs only rarely. Again, this will necessitate removal of combustibles from the affected area, isolation of the sprinkler system, and plugging of the sprinkler heads in that area. The attachment of new range pipes and alteration of other pipe work will require further isolations. It is important that such work is planned and undertaken so that the isolation of sprinklers in the trading part of the floor is minimised.

Based on the information in [5], and on the assumption that separate isolation valves are provided for major stores and each level of a department store, it is estimated that these zones are isolated about one third of the time that a specialty shop zone is isolated. Thus it is reasonable to consider that the sprinkler zones associated with major stores are isolated for 0.005 of the time (being active for 99.5% of the time).

APPENDIX 7.3

ROOF SPRINKLER PROTECTION

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APPENDIX 7.3 ROOF SPRINKLER PROTECTION

Sprinkler protection in high spaces does not provide as effective protection against fire growth and spread as sprinklers under lower ceiling heights. There are two reasons for this. Firstly, as a smoke plume rises above a fire, it entrains ambient air from the surroundings, cooling and diluting the combustion products. In high spaces this effect is more marked, and the gases reaching ceiling level are significantly cooler than they would be at lower ceiling heights. As a result, it takes longer for the sensitive element of a sprinkler to heat up to its operating temperature and the fire has to be larger to cause sprinkler operation. The sprinklers may not operate at all, even for relatively large fires. If the fire is larger and sprinklers activate, the sprinkler spray may not be effective in penetrating the fire plume and reaching the burning surface to bring about extinguishment or fire control.

The temperature and velocity of the fire gases rising from a fire and spreading across a ceiling can be calculated using a set of correlations developed by Alpert [35] based on theoretical analysis and comprehensive experiments carried out on fires of steady heat release rate. The experiments were carried out under large unconfined ceilings with fire sizes in the range 0.7MW to 98MW and ceiling heights in the range 4.6 to 15.5m. Away from the plume impingement region, the temperature T_g of the fire gases is given by:

$$T_g = (5.38/H)(Q/r)^{2/3} + T_o$$

and the radial gas velocity U_g is given by

$$U_g = 0.195\ Q^{1/3}\ H^{1/2}\ r^{-5/6}$$

where H is the height of the ceiling above the fire and r is the radial distance.

These correlations have been incorporated into a program DETACT T2 which calculates sprinkler actuation time based on assumed t^2 fires. The results from runs of this program with different ceiling heights, sprinkler sensitivities and fire growth rates are shown in Table A7.4. In carrying out the calculations it has been assumed that a typical standard response sprinkler has an RTI of 200 $(m.s)^{1/2}$ and that a fast response sprinkler has an RTI of 50 $(m.s)^{1/2}$.

TABLE A7.4 TIME TO SPRINKLER OPERATION AND FIRE HEAT RELEASE RATE AT SPRINKLER OPERATION

	medium growth rate fire				*fast growth rate fire*			
ceiling height/ m	*standard response sprinkler*		*fast response sprinkler*		*standard response sprinkler*		*fast response sprinkler*	
	time (s)	*heat release rate (kW)*	*time (s)*	*heat release rate (kW)*	*time (s)*	*heat release rate (kW)*	*time (s)*	*heat release rate (kW)*
3	289	979	216	550	184	1,597	134	840
5	351	1440	280	919	220	2,280	167	1,300
10	523	3209	461	2,490	315	4,650	260	3,180
15	720	6,082	662	5,140	420	8,290	366	6,270
20	929	10,100	875	8,980	530	13,100	477	10,700

Because real rooms do not have unconfined ceilings, a layer of hot smoke builds up below the ceiling jet, and in reality the jet temperature is likely to be higher than that given by Alpert's correlations. This means that predictions using DETACT are likely to be conservative in the sense that longer sprinkler operation times will be calculated than would be expected in practice. Nevertheless the principle still holds that sprinklers in high ceilings take longer to operate and are likely to be less effective than sprinklers in lower spaces. It is a fallacy to assume that because sprinklers are present in such circumstances that they confer significant fire safety benefit. The calculations suggest that sprinklers will not be very effective above heights of 10m, though this might be increased to 15m if fast response sprinklers are used.

It is clear that at somewhere between 10 and 15 m ceiling height, whether fast response sprinklers are used or not, for both fire growth rates the sprinklers are not controlling the fire soon enough to a low heat release rate. On the basis of the above calculations it is recommended that sprinklers not be relied on at roof level as part of the safety strategy above 15m if fast response sprinklers are installed and above 10m if standard response are used.

APPENDIX 8.1

RATE OF FIRE STARTS

APPENDIX 8.1 RATE OF FIRE STARTS

From NSW fire statistics for three years (93-95) it is found that there were 1241 fire incidents recorded where the fire brigade attended a fire in a retail premise. Advice on the frequency of reporting of fire incidents suggests that at least 90% of fire incidents were reported in this period of time. Therefore, it can be assumed that the total number of fire incidents attended by the brigade is $\frac{1241}{0.9} = 1378$.

As noted in Chapter 8, there are a significant number of fires to which the brigade are not called and the above number can be multiplied by a factor of 5. Thus the average number of fire starts in NSW per year is taken as $\frac{1378 \times 5}{3} = 2296$.

The total gross lettable floor retail area for NSW as recorded for retail centres registered with the Property Council of Australia [37] is 3.6 x 10^6 m^2; however this area by no means represents the total retail area (strip shops and smaller retail outlets are not registered by the above organisation) which is estimated as being at least 2.5 to 3 times this value. Therefore an estimate of the number of fire starts per unit area is:

$$\frac{2296}{2.5 \times 3.6 \times 10^6} = 2.55 \times 10^{-4} \text{ /yr/ m}^2$$

Applying this to the mall situation being studied in Chapter 9 it is found that over a life of 50 years there will be, on the average:

$2.55 \times 10^{-4} \times 76000 \times 50 = 970$ fire starts.

APPENDIX 10.1

OCCUPANT RESPONSE - FACTORS AFFECTING BEHAVIOUR
(contributed by W Saunders)

APPENDIX 10.1 OCCUPANT RESPONSE - FACTORS AFFECTING BEHAVIOUR

A10.1.1 Introduction

To determine the current fire safety requirements for shopping centres it is necessary to understand the response of occupants to shopping centre fire emergencies. As part of the Fire Code Reform Centre (FCRC), Project 6 (fire safety of low-rise sprinklered shopping centres), an investigation was conducted into the factors affecting the behaviour of shopping centre occupants. The investigation considered a number of approaches to collecting information. These included accounts of retail fires, as reported in international literature, detailed statistical information on retail building fires in the USA and Australia (summarised elsewhere in the Project 6 Report), structured interviews with shopping centre management, anecdotal accounts from staff and shoppers of retail fire incidents and observations of evacuation exercises in shopping centres. Although the scope and quality of the international literature reports are variable and in some cases the premises do not bear much resemblance to Australian shopping centres, the reports did provide valuable information, as well as a starting point, for identifying the most significant individual, social and environmental factors, that influence behaviour in fire emergencies.

A10.1.2 Shopping Centre Occupants

The investigation divided the occupants into two main groups - shoppers and shopping centre employees. Shoppers were classified by gender, age, physical mobility and whether alone or accompanied by others. Employees were divided into the following sub-groups - centre management and staff (security, cleaners, maintenance workers), department and major store managers, department and major store shop assistants and independent shopkeepers.

A10.1.3 Social Factors

Large low-rise shopping centres are by nature task oriented, hierarchically organised environments. As a result of the commercial transactions that take place, there is also an emphasis on security and supervision of occupants. People, whether employees or shoppers, have defined roles and responsibilities and are generally involved in purposive activities. Although individual factors such as age, gender, and physical mobility may influence response to an emergency situation, this study found that social factors appeared to be the most important determinants of behaviour. In contrast to residential fires, where much reliance is placed on individual definition and response to an emergency, the decision-making behaviour of shopping centre occupants, in an emergency, is significantly influenced by their role in the occupancy and the behaviour and communications of others. This seems to be supported by studies of similarly controlled environments [38], where it has been found that decision-making in emergencies reflect the way that an organisation operates, how groups form, what communications occur, and who can make the decisions that affect others. In general, behaviour in a public place such as a shopping centre, appears to be as much a response to the social environment, as to the physical effects or signs of the emergency itself. It is the occupational role (shopper or employee) that determines knowledge of and familiarity with, the building environment (including exits), emergency procedures, warning systems, lines of communication, chains of command and responsibilities to others.

Methodology

Due to the infrequent and unpredictable nature of any building fire emergency, it is difficult to collect sound data on the decision-making behaviour of people involved. Most of the available data comes from:

i) interviews, questionnaires and case studies from actual emergencies;

ii) experiments that try to recreate or simulate, emergency situations;

iii) field studies and observations during emergencies.

iv) fire incident statistics, insurance reports, coronial investigations, etc.

Each of the data collection methods is subject to problems of reliability, validity, ethics and accessibility. This investigation initially considered collecting the information on response to retail fire emergencies, by administering carefully designed questionnaires to employees and shoppers. The purpose of the questionnaires was to present a hypothetical set of shopping centre fire emergency scenarios and record behaviour in response to the situation. The scenarios would describe various physical and social cues associated with a fire and the questionnaire would provide a list of possible actions from which to choose. The physical cues included those more directly related to a fire (level and extent of smoke and flames, degree of heat, etc), and those indicative of a possible fire (alarms, sirens and warnings). Social cues related to the behaviour, communications and instructions of others. Categories of actions describing response to building fire emergencies, to be presented to participants, were obtained from research findings in the field of human behaviour in building fires [17,38-43]. Using anecdotal experience of fire incidents as reported by retail employees and shoppers, the list of behavioural choices was modified and those appropriate to a retail environment were selected. From the selected actions, in response to described cues, the probable responses of various occupant groups could be calculated. However, given the number of groups and sub-groups involved and the number of possible scenarios and actions, the time constraints involved in obtaining a large and representative sample for statistical analysis, was prohibitive. In addition, retail fire emergencies are relatively rare occurrences, so few shoppers and retail staff have experienced the situation, and therefore may not have an accurate insight into what they would do in a shopping centre emergency. The investigation decided on an approach which combined a number of different sources of information. International fire literature provided certain valuable information and statistics and this was combined with interviews with experienced shopping centre staff and management.

A10.1 4 Rationale

i) Where reports are available, documented emergency incidents provide useful data on the observed behaviour of emergency services, staff and shopper in response to a range of incidents in shopping centres. Statistics on fatalities from USA [15], covering a very large number of fires shed light on circumstances such as time of day, day of week, month, state of consciousness, location/cause of fire with respect to victims, age gender, etc. According to reviews [24], the small number of fatalities in retail premises (In the USA, 86 per 77 960 fires in the period 1983 - 1993, with no recorded fatalities in Australia for the same period) and their circumstances - the majority of the victims were impaired (bedridden, very old or very young), or asleep at the time of the fire, or intimately involved in the ignition of the fire. Flammable liquids (usually petrol) appear also to have been involved in a significant number of single and multiple retail fatalities. It may be assumed that the chances of occupants being asleep or involved with flammable liquids, during normal retail hours in modern shopping centres, are very low. However, more information on occupant behaviour, during these times, is required for determining fire safety requirements for shopping centres.

ii) Experienced shopping centre management personnel were considered an appropriate source of information concerning retail fire incidents. The nature of their position and everyday responsibilities means that centre managers have many opportunities to be informed of, participate in, and observe the behaviour of others, in emergency incidents. This is substantiated by the interview reports of centre management that "we are the first to be notified if anything unusual occurs" Centre management is the first to be informed, by other shopping centre employees (retail, security, maintenance, etc), in an emergency. They are expected to provide the expertise to deal with maintenance problems, first aid and minor incidents and form the interface between the shopping centre and emergency services/external authorities in more serious situations. There is an expectation from shop keepers that centre management will provide advice, expertise and assistance in the resolution of problems.

iii) Normally shoppers have little contact with centre management. However they do have contact with retail staff and other employees whose instructions and communications either originate from, or are conveyed to, centre management. In an emergency the general public turns to shop assistants, security staff, cleaners, (any one with a uniform or badge, indicating that they work in the centre) for advice, assistance or information on the situation. These observations are supported by anecdotal evidence from shoppers involved in false alarms, shopping centre evacuations, fire incidents, etc and confirmed by retail staff reports concerning shopper behaviour in false alarms and emergencies.

In summary, centre management staff represent the best available source of information on the behaviour of shopping centre occupants .

- They have generally experienced a number of shopping centre false alarms, emergencies and evacuations, in a range of shopping centres.
- As a result of this experience, they have valuable insights into the behaviour of staff and shoppers in response to the cues associated with emergencies as well as their behaviour in false alarm situations.
- Because their responsibilities include the everyday security, maintenance and administration of shopping centres, centre management and security staff are generally the first to be notified of anything untoward in the shopping centre. This puts them in a good position to be aware of the nature of various incidents and subsequent occupant response to unusual situations.

- They are acquainted with emergency training and evacuation procedures and are familiar with the differences in occupant behaviour and response to drills as compared with real emergencies.

A10.1.5 Conduct of the Investigation

Shopping centre management personnel were interviewed on a voluntary basis with the reassurance that their identity would remain anonymous and confidential. The purpose of the investigation was explained and its importance in contributing to improvements in fire safety. Frankness was stressed in the interview. Participants were asked to recount their experiences of false alarms and specific emergencies (particularly fires in shopping centres). It was emphasised that information on the causes of the incidents, the extent and behaviour of staff and shoppers, was particularly important. As part of the process, they were asked to describe the centre's detection and warning systems, staff responsibilities and emergency procedures for the shopping centre. They were also asked to identify any problems associated with the population demographics of the area, staff turnover, communications and daily or seasonal fluctuations in shopper population. Finally, they were asked to use their expertise to predict the response of shopping centre staff and shoppers to various fire scenarios.

Specific questions posed to centre managers related to:

- The extent of evacuation drills and training conducted in the centre.
- The percentage of department, major and specialty stores that would evacuate shoppers under various cue combinations.
- The percentage of shoppers that would voluntarily leave these stores or the shopping centre, under various cue combinations.
- The most influential cues on the decision-making behaviour of shopping centre staff and shoppers in emergencies.
- Who makes the decision to evacuate.
- The circumstances that determine which exits are chosen for evacuation.
- The willingness or otherwise of shoppers to use exits, other than those used to enter the centre.
- The time taken for staff and shoppers to decide to evacuate.
- The circumstances that determine the extent of evacuation.
- The actual and perceived function and responsibilities of shopping centre staff in fire emergencies.
- The time intervals involved in deciding to evacuate and informing staff and shoppers.
- The nature and extent of responsibility or control shared between the attending fire brigade and centre management in a fire incident.

A10.1.6 Results:

Many of the recollected incidents involved false alarms caused by vandals, power surges, accidents, water pressure fluctuations, burnt food, etc. Most of the incidents reported were small fires, confined to the object of ignition (fires set in rubbish bins or toilets) that activated alarm systems, or small electrical fires that resulted in power loss to a localised area of the centre (e.g. an individual tenancy or shop). Other reports concerned smoke logging of small and large stores and malls, caused by such things as fires in compactors, faulty diesel air conditioning pumps, etc.

A10.1.7 Occupant Responsibilities:

Although all shopping centres have detailed procedures manuals outlining responsibilities in emergencies, centre management essentially controls decision-making in emergencies, unless under advice and instruction from the fire brigade, police, etc. Centre management has the authority to override instructions of any tenants in matters of public safety. There is a reliance and expectation that centre management will provide advice and guidance to all retail tenants This is substantiated in the accounts of interviews with centre management and shopkeepers. Finally, despite warden structures being in place, in practice, in an emergency, centre management relies on its own staff (security, cleaning and maintenance staff) to instruct occupants. The fire brigade acts as a final authority on the necessity and extent of evacuation. There was general consensus amongst centre managers on the following occupational responsibilities:

i) Centre management

- responsible for security and all first aid in the centre and for the safety of shoppers in walkways and malls.
- intercept and control the public alarm and warning systems (during normal trading hours) and decisions regarding when to sound the various alarms, when to evacuate and the extent of the evacuation. (during trading hours the alarm system is usually switched to MANUAL. It is on AUTOMATIC for the rest of the time).
- deal with notifications by shop keepers, store managers and staff (security, cleaners, maintenance) of anything "untoward" in the centre.
- liaise with the emergency services.
- test alarms and smoke extractors, etc.
- check and oversee renovations, refits, maintenance, etc (ie. that procedures and plans conform to safety requirements).
- maintain power mains, services and systems to shopping centre and tenants.

ii) Department/Major Store Manager:

- appointment of wardens and the emergency training and evacuation procedures
- safety of staff and shoppers within the store
- instructions to staff and shoppers in an emergency
- timing and extent of evacuation unless/or under advice/instruction from centre management or emergency services
- choice of exits to be used in an emergency

iii) Independent Shop Keeper:

- safety of staff and shoppers within the store
- evacuation of staff and shoppers from the premises, in an emergency

A 10.1 8 Behaviour of Shoppers in Emergencies

Observations by centre management, retail staff and security, combined with anecdotal reports of shoppers, indicate, that in general, shoppers are not familiar with the public alarm systems, evacuation procedures or emergency exits, in shopping centres. Instead, they rely heavily on the instructions of staff and/or emergency services, in an emergency. Centre management and retail staff report however, that most shoppers will co-operate with staff and emergency services and follow instructions. In summary:

- Shoppers are influenced by the behaviour and instructions of those perceived to have information or expertise in the situation. They take their decision-making cues from significant others.
- The significant others include retail staff, security, (anyone with a badge or uniform indicating that they work in the centre), emergency services and in some cases, other shoppers.
- When a public alarm sounds in the centre, most shoppers continue shopping, browsing or eating, maybe pausing momentarily to look around and observe the reactions of others.
- If other shoppers or staff appear unconcerned, most shoppers continue with their activities. For prolonged alarms or multiple cues (smelling/seeing smoke, fire sirens, unusual activities on the part of staff, etc), the most common shopper reaction is to seek information by approaching a staff member (retail assistant or security), or conferring with other shoppers.
- In the case of a fire or emergency within a shop, shopper behaviour is determined by the behaviour and instructions of the staff. If the staff continue trading, shoppers tend to remain within the shop and continue shopping or browsing. If evacuation is necessary, shoppers are generally prompt in obeying instructions to leave the shop.
- For partial or localised evacuation, many shoppers move to another area to continue their business if possible, rather than leave the centre entirely.
- When evacuation of the whole centre is necessary, shoppers prefer to make their way towards, or leave by the entrance, they came in by. Reasons given for their preferred exits are familiarity and convenience (public transport location, car parked nearby, rendezvous point for meeting others, etc).
- Most shoppers reported being reluctant to use the emergency exits to leave the centre and would only do so if directed. Shoppers indicated that they did not know where the emergency exits were, did not know where they would come out and were unsure if they were permitted to use them. Some shoppers felt further discouraged by notices on

emergency exits, such as "Staff Only", "To Be Used in an Emergency Only" or "This Door is Alarmed", etc. Centre managers mentioned that many shoppers were afraid to use emergency exits because they were "unfriendly places" used by teenage gangs to hide or fight in.

- The behaviour of other shoppers was said to be a significant determinant of direction of movement of shoppers. People tend to follow the crowd when evacuation is required and move in the same direction as other people.
- The behaviour of retail and security staff and emergency services personnel is also a decisive factor in shopper assessment of the situation. As well as following directives from these sources, shoppers reported being affected by the demeanour of staff, in the situation. If retail staff, security and fire brigade personnel appear calm and unconcerned (in the case of false alarms or small incidents), shoppers will, on the whole, take little notice of their presence and assume that the situation is under control and not serious.

A10.1.9 Emergency Procedures:

From emergency procedures manuals, training documentation, interviews with centre management and staff and supplemented by observed evacuation drills, a summary of shopping centre emergency procedures is presented and illustrated in Figures A10.1.1 to A10.1.4.

i) Centre Management, Wardens (Figures A10.1.1 and A10.1.2)

Upon receipt of an alarm or notification from staff, the emergency controller or deputy checks the Fire Indicator Panel (FIP) to determine the location of the alarm (if not known) and sends or radios security or wardens to investigate and report back. Whilst awaiting the fire brigade, a determination is made of the cause and status of the signal (false alarm, mechanical cause or fire, etc). Wardens are then instructed to take up their positions. Centre management determines the level of severity, shuts down power, gas, etc if necessary and decides (depending on the size), whether to fight the fire. If required, the public alarm system is activated and instructions given to staff, shopkeepers and shoppers. Centre management then decides whether evacuation is necessary and its extent. Areas adjacent to the fire are evaluated on their merits. This judgement depends on the size of the fire, amount of smoke and levels of toxicity. Centre management relies on the advice and instruction from the attending fire brigade in doubtful situations.

ii) Department/Major Store Manager (Figure A10.1.3)

If a fire occurs in the shop, the manager notifies centre management and for small fires, or if safe to do so, will attempt extinguishment. If the fire is not in the store but elsewhere in the centre and the public alarm sounds, the manager awaits instruction from centre management. Upon receipt of a notification of fire or the building's ALERT signal, staff are instructed to stand by. If the centre's EVACUATION signal sounds, the manager directs staff to keep working until further notification. The manager then decides on further action using their own assessment of the situation, supplemented with advice from centre management. Wardens are told the instructions to be given to staff and shoppers. If evacuation is necessary, staff are told to take up positions at exits to prevent re-entry of shoppers and for security purposes.

iii) Independent Shop Keeper (Figure A10.1.4)

If a fire occurs in the shop, they will notify centre management and for small fires, or if safe to do so, will attempt extinguishment. If the fire cannot be extinguished, the shopkeeper will evacuate shoppers from shop and secure cash and stock. The final act is to close the shop and evacuate. If the fire is not in the shop, but elsewhere in the centre, and the public alarm sounds, the shopkeeper awaits instruction from centre management, security or wardens. Shop keepers usually continue trading, unless advised otherwise.

A10.1.10 Conclusions:
Occupant Behaviour

i) Shoppers are reluctant to use emergency exits, preferring to use the entrance that they are familiar with. They do not enter the shopping centre by emergency exits, are not familiar with them, find them unfriendly places, do not know where they come out and in general, have no reason to use them to exit the shopping centre.

ii) In an emergency, shoppers tend to ask staff (shop keepers, security, etc) for information and advice and/or observe the behaviour of other shoppers. In response to alarms, most shoppers continue shopping or browsing, but also may ask staff for information and/or advice.

iii) Shoppers tend to observe the behaviour of the fire brigade when they arrive and take their cues from the degree of action - if the fire fighters appear calm and unhurried, shoppers take little notice of their presence.

iv) The majority of shoppers will promptly follow directions from shop keepers, security staff, wardens and the fire brigade. Their choice is determined when shop keepers close shops.

v) When instructed to leave a shop or area, many shoppers will move to another area of the shopping centre, if possible, to continue their business.

vi) Due to commercial considerations, department, major store managers and specialty shop keepers are reluctant to evacuate shoppers, unless it is clear that there are issues of public safety or security, or, they are instructed to do so, by centre management or emergency services.

vii) Shop keepers, security, cleaners, tend to telephone or radio centre management first in an emergency, or upon discovering any other unusual situation.

viii) The majority of shop keepers will follow procedures and directions from centre management, security staff, wardens, emergency services.

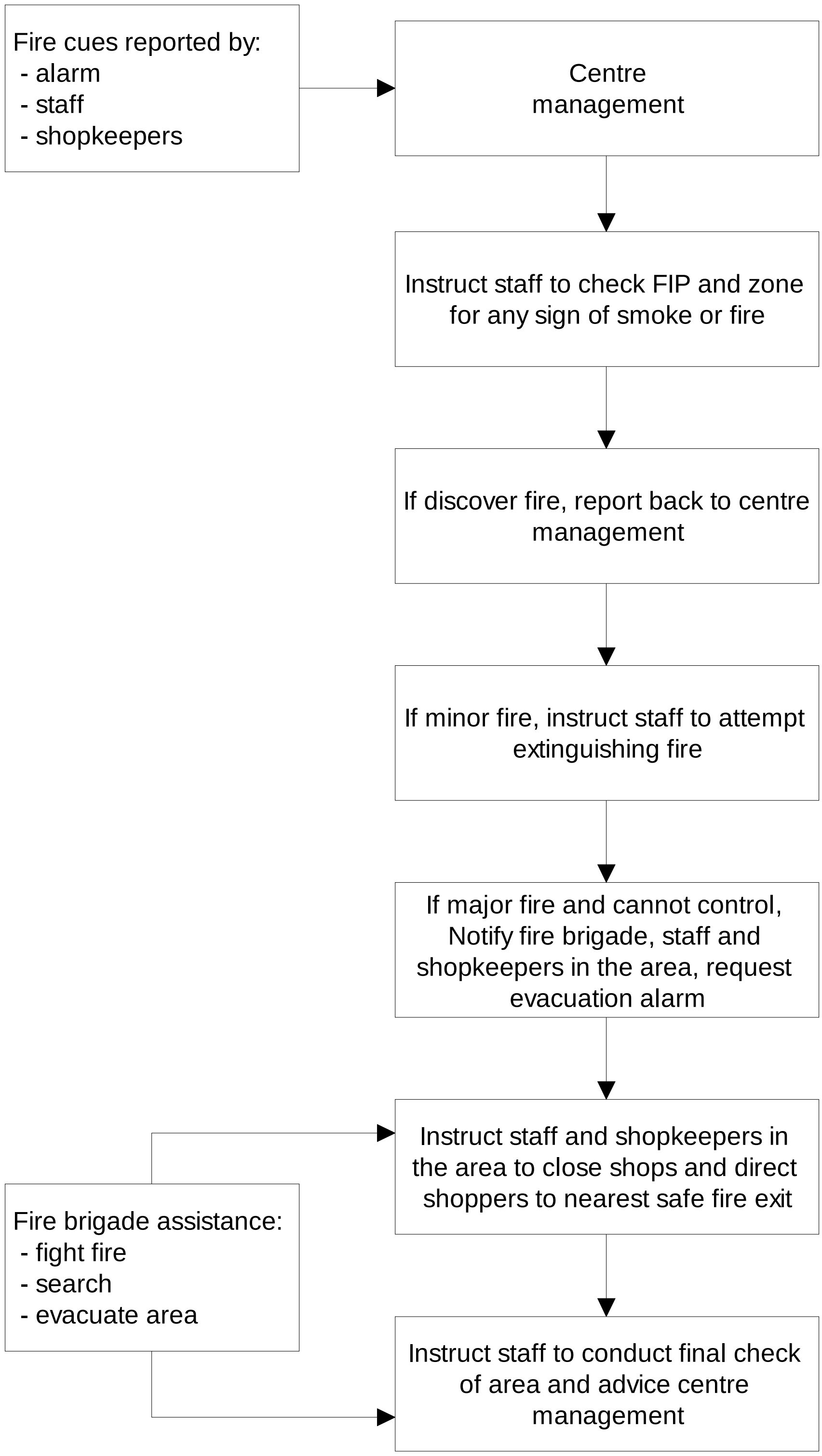

FIGURE A10.1.1 DUTIES OF CENTRE MANAGEMENT

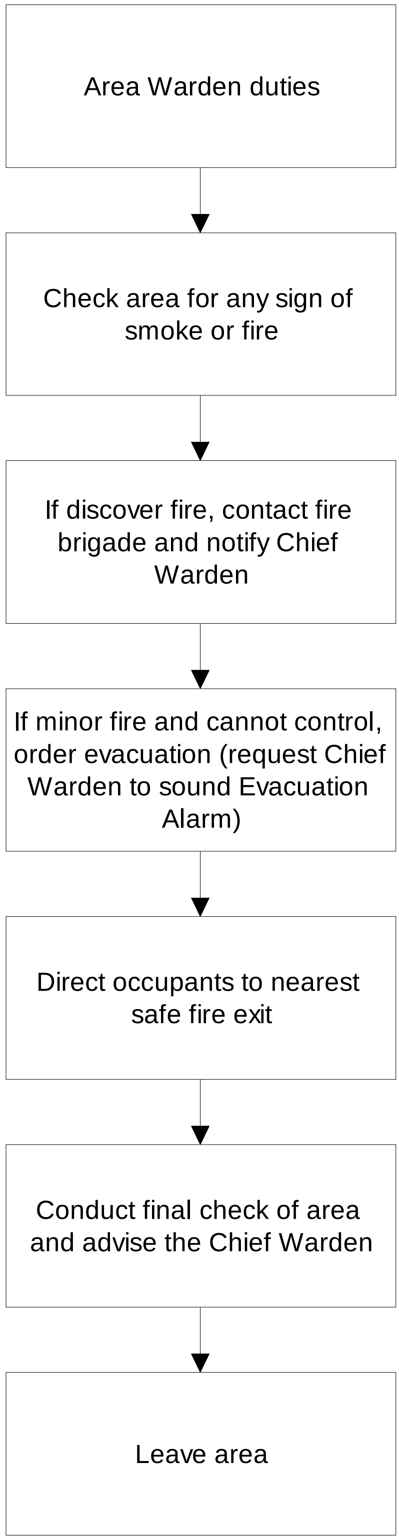

FIGURE A10.1.2 DUTIES OF AREA WARDENS

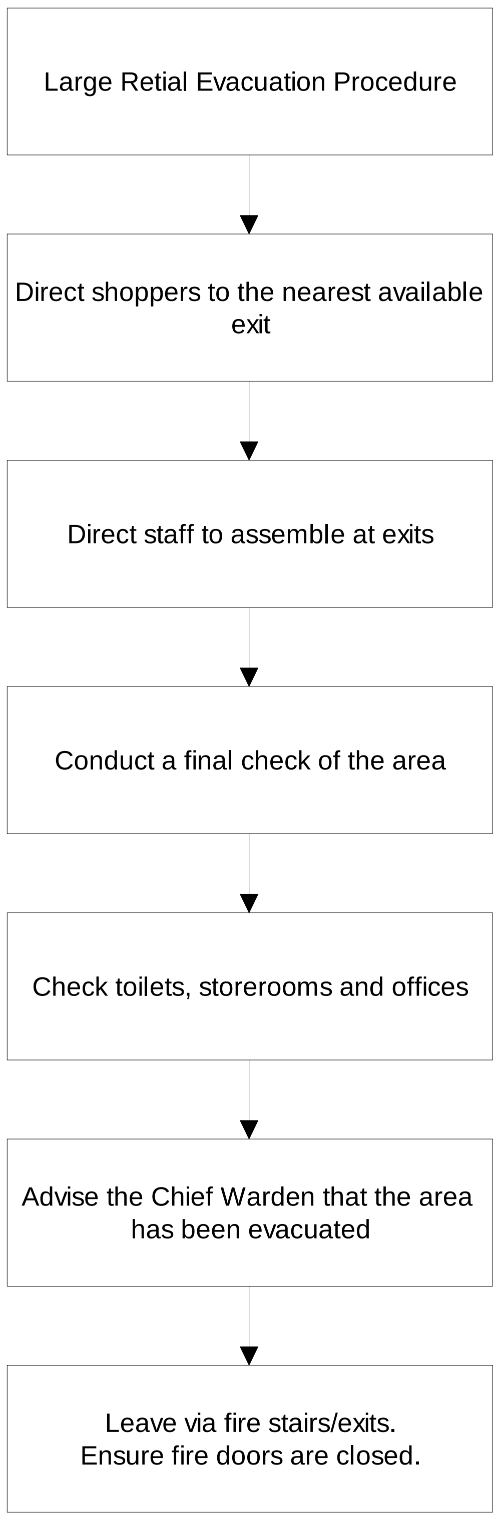

FIGURE A10.1.3 DUTIES OF DEPARTMENT/MAJOR STORE MANAGER

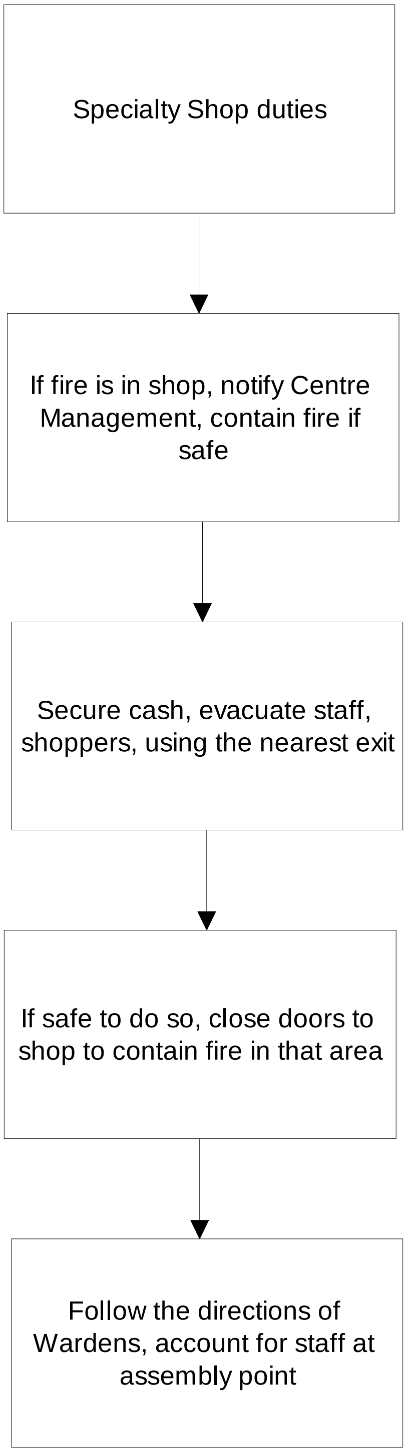

FIGURE A10.1.4 DUTIES OF SPECIALTY SHOP OWNERS

APPENDIX 10.2

EMERGENCY PROCEDURES FOR A MAJOR STORE

APPENDIX 10.2 EMERGENCY PROCEDURES FOR A MAJOR STORE

NON-SMOKING POLICY

All supermarket premises are considered as “smoke free working environments”. This includes: stores, head and state offices and distribution centres.

FIRE

Fire Wardens

There are a number of appointed fire wardens in the store. Usually department managers are given this responsibility.

Names of the fire wardens are positioned on notice boards where the fire plan is located. In the case of a fire in the store, these people are responsible for ensuring all correct procedure are adhered to.

Fire Wardens in your store are: ______________________________

____

____

Emergency Exits and Evacuation Assembly Point

The fire plan shows the location of all emergency exits in the store. Pay attention to where these are located, as you may need to evacuate through one of these in the case of a fire.

The store also has a designated evacuation assembly point located off the supermarket premises. This location is mapped out on the fire plan and you will be shown where to assemble. In the case of evacuation, this is the point where all staff must gather.

Hand Siren

There are hand sirens located in the store.

They are used for evacuation purposes in conjunction with “Red Jezzabell” warning.

The hand siren can only be used by authorised personnel.

Again, when the hand sirens is sounded you must evacuate the premises.

Housekeeping

Every staff member has a responsibility to prevent aisles or emergency exits from becoming blocked or congested. There should be also be clear access at all times to fire protection equipment eg. fire extinguishers and hose reels. Always observe the non-smoking policy and ensure containers of flammable liquids are covered.

Red Alert

A situation may arise in the store where a fire has broken out but it does not require the premises to be evacuated. It may be a problem that can be easily contained.

“Red Alert” will be announced over the loud speaker three times, as well as the section in which the fire is located. At this point, you are not expected to do anything, this call must be actioned by the fire wardens.

Stay in your work are and continue working, unless and until you are told otherwise.

If you discover a fire, report it immediately to your manager or fire wardens.

Red Jezzabell

“Red Jezzabell” will be announced three times over the loud speaker.

When you hear this message, stop what you are doing, don’t panic and evacuate the building from the closest fire exit.

The hand siren is used in conjunction with the “Red Jezzabell” warning.

Do not stop to collect any of your belongings or to take anything with you. Remember property can be replaced—you cannot be!

Once you have evacuated the building, head for the designated assembly point where everyone is to be accounted for from the attendance book.

If there are any customers near you when evacuation is required, explain to them what is going on, as ask them to accompany you through the exit.

Extinguishers

There are a number of different fire extinguishers located in different areas in the store. The location of all extinguishers is mapped out on the fire plan. Each department also has it’s own extinguisher/s. These are chosen specifically for the types of fires that may occur in the department.

Ensure you note the location of the extinguisher/s in your department. You will be shown how to use them.

APPENDIX 10.3

STUDY OF USA DEPARTMENT STORE

APPENDIX 10.3 STUDY OF USA DEPARTMENT STORE

According to the UBC building code [45], unsprinklered department stores can be constructed in the US having a total floor area of 3800 m^2 or 61.5 m x 61.5 m. This store will most commonly have two 1.5 m doorways (glass sliding doors) at the front leading to the open street. In the event of a fire, the occupants will use these means of egress in most cases in preference to using other emergency exits.

Assuming that occupant flow rate through exits is 1 person per sec per m, the travel speed across floor is 0.6 m per sec, and that the maximum population is 662 (based on Appendix 10.4) rather than 1330, then the time for evacuation of the store can be calculated.

Assuming that the front doors (total width = 3m) are used:

$\frac{662}{3.0} = 220$ seconds plus an allowance for travel time of approximately 30 seconds suggests an overall movement time of about 3 to 4 minutes. This does not allow for any “decision-making” or pre-movement time.

APPENDIX 10.4

ALTERNATIVE FLOOR AREA PER PERSON CALCULATIONS

APPENDIX 10.4 ALTERNATIVE FLOOR AREA PER PERSON CALCULATIONS

Based on the weekly door count data for the population flow associated with the shopping centre used for the detailed study reported in Chapter 6, the 95th percentile value taken over a period of several years is determined to be 296,000 per week. This corresponds to approximately 1.74 times the population count for a typical week.

Assuming that shoppers spend an average of 2 hours in the shopping centre, the population of the centre averaged over the operating hours of the typical week (excluding Sundays) is 4,610. If the shopping period is 3 hours, the corresponding population is increased to 6,550. The 95th percentile values are 8,039 and 11,420 respectively. Data from centre management indicates that the average period of time spent in a shopping centre is 2 hours.

The shopping centre considered has a total rentable sales area of 58,000 m^2 and an additional total walkway/concourse area of 10,000 m^2. Subtracting areas associated with the voids and escalators associated with the concourse, reserve and storage areas associated with single-level major stores, and lifts, storage areas, toilets and escalators associated with the multilevel department store, a total area of 62815 m^2 of sales area is obtained. Of that area, 8160 m^2 is associated with the two upper levels of the department store which are not accessible from the outside or via the mall. The lower two levels are accessible from street level. The BCA (Table D1.13) [4] recommends that sales areas at a level entered directly from the open air or any lower level should use an area per person of 3 m^2 to calculate the population, whereas for other levels and walkway areas, a value of 5 m^2 per person is recommended. Based on these recommendations by the BCA, the shopping centre population is calculated to be 18660.

If it is assumed that the average time shoppers spend in the shopping centre is 2.5 hours (but as stated above, the average period is two hours), the corresponding 95th percentile population for the centre is 9,730. This is about half the BCA calculated value of 18660. Accordingly, the population density differentiated in accordance with the BCA recommendations can be taken as 6 m^2 per person for mall areas and sales areas on accessible levels and 10 m^2 per person for other levels and walkway areas.

APPENDIX 11.1

SMOKE FILLING RATES FOR SPRINKLERED FIRES

APPENDIX 11.1 SMOKE FILLING RATES FOR SPRINKLERED FIRES

In sprinklered fires, smoke production tend to be limited in duration due to the wetting and cooling effect of the sprinkler spray on the fuel. When the sprinklers are activated in a fire, the part of the fuel which is being consumed may continue burning until it is fully consumed. Any fuel located nearby but is shielded from the water spray may also ignite and burn. The amount of smoke produced is limited by the extent of burning and eventually smoke production will cease when all burning ceases.

Smoke filling rates have been determined based upon smoke transmissivity measurements at the North and South end of the test structure in the burn hall [11]. In order to be able to define a smoke interface for the purpose of determining the height of the smoke layer, it has been assumed that the smoke interface corresponded to transmissivity values of 0.5, ie. levels of smoke in which only 50% of the light is transmitted. Based on this criteria, the height of the smoke layer has been determined and are shown in Figures A11.1a and A11.1b for Test 1 and Test 3 respectively.

The corresponding volume of the burn hall at each measurement point is shown in Table A11.1a.

TABLE A11.1A MEASUREMENT HEIGHTS AND CORRESPONDING SMOKE VOLUMES

measurement point	*height (m)*	*volume above height (m^3)*
SD1	10.75	604
SD2	9.75	1007
SD3	8.75	1410
SD4	7.75	2033
SD5	6.75	3163
SD6	5.75	4578
SD7	4.75	6246
SD8	3.75	7913
SD9	2.75	9580
SD10	1.75	11247

Offsets are applied to the data points to align the data to a common origin and the data points are then curve-fitted to establish a simple relationship for smoke filling for sprinklered fires. The curve-fitting relationship is determined as:

$$V = 12000\left(1 - e^{-t/240}\right) \quad \text{(A11.1)}$$

where V is the smoke volume (m^3) and

t is the elapsed time in seconds.

For most practical purposes, t corresponds to the time after which the fire begins to grow rapidly. The resulting comparisons of smoke filling times (averaging the North and South end measurements) with the predictions given by Equation A11.1 are shown in Figure A11.1C.

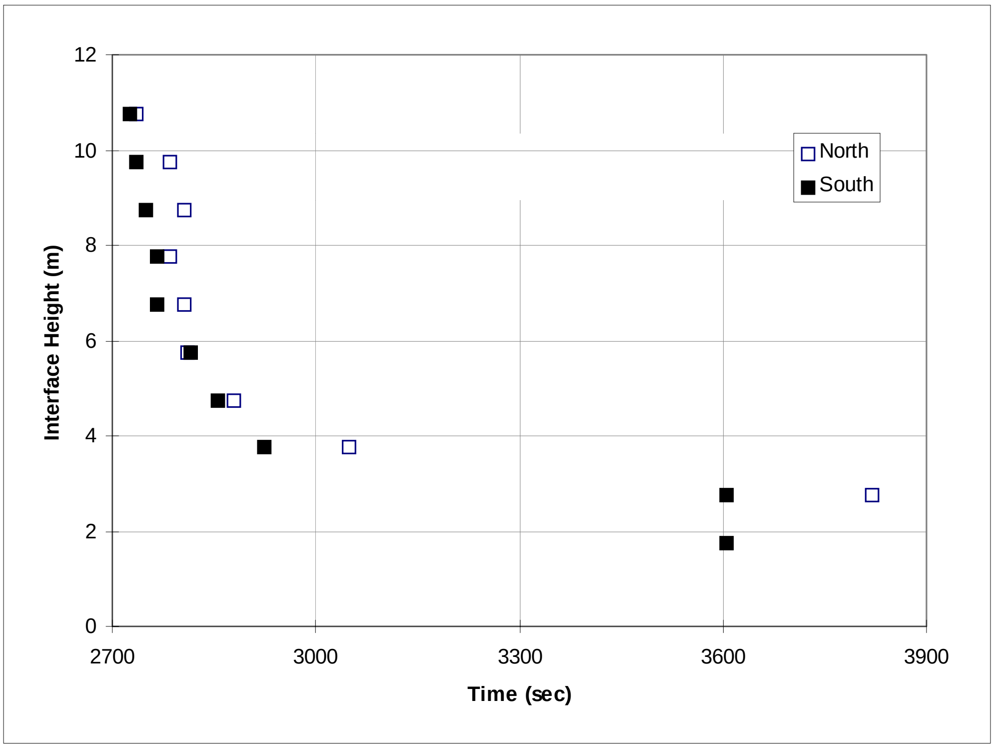

FIGURE A11.1a - SMOKE LAYER HEIGHTS, TEST 1

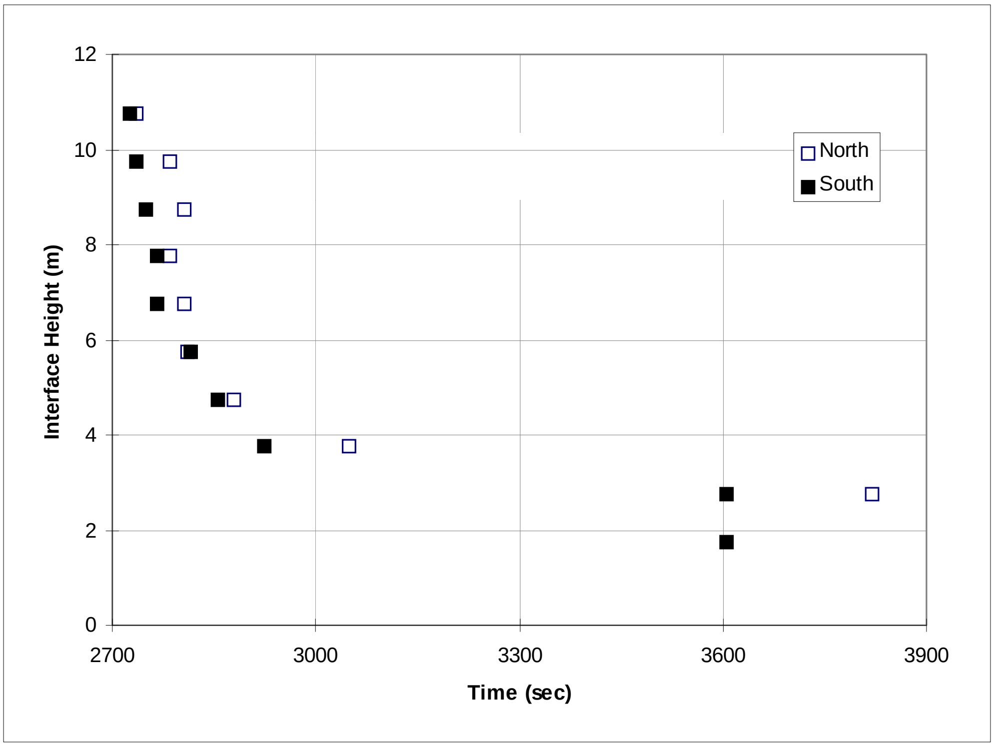

FIGURE A11.1b - SMOKE LAYER HEIGHTS, TEST 3

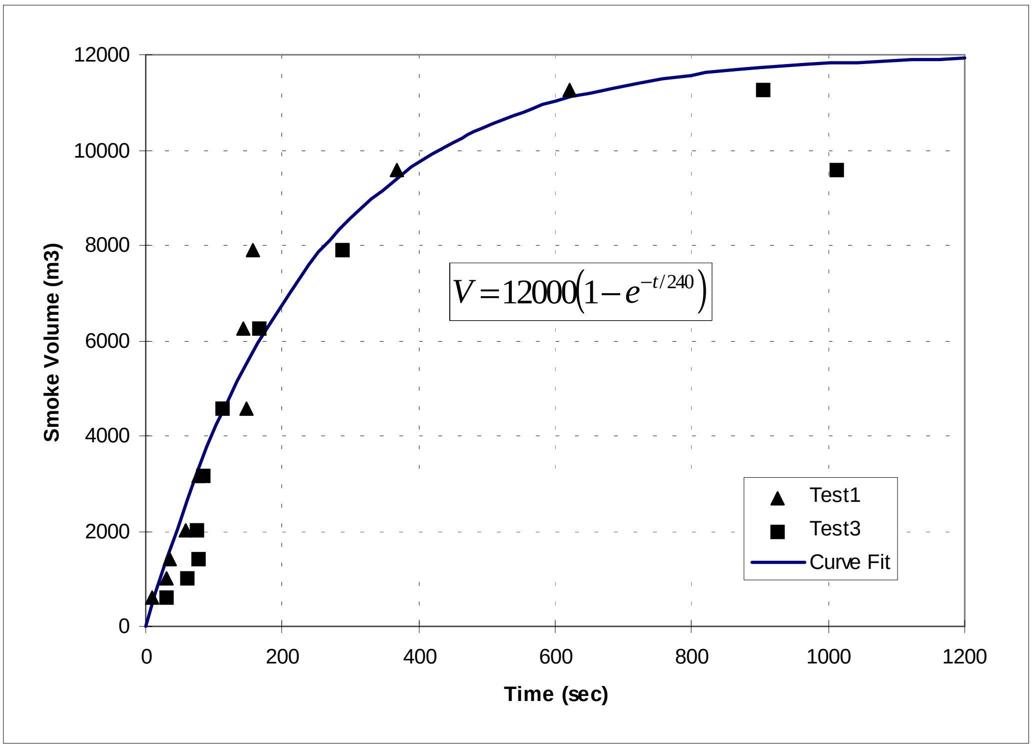

FIGURE A11.1c SMOKE VOLUME GENERATION FOR SPRINKLERED FIRES

The rate of smoke production is simply the differential of Equation A11.1, ie.

$$\frac{dV}{dt} = 50e^{-t/240} \qquad \text{(A11.2)}$$

As explained in Chapter 11, the situations tested had the sprinkler heads located at the least effective positions, and the situation defined by the expression for Equation A11.2 corresponds to a Category "C2-4" fire. Categories "C2-3" and "C2-2" are fires which have smoke production rates reduced to 50% and 25% respectively of that associated with Category "C2-4". Generally, Equation A11.2 may be expressed as:

$$\frac{dV}{dt} = \frac{k_c}{60} e^{-t/240} \qquad \text{(A11.3)}$$

$$\text{such that } k_c \begin{cases} = 3000 \text{ for Category "C2 - 4"} \\ = 1500 \text{ for Category "C2 - 3"} \\ = 750 \text{ for Category "C2 - 2"} \end{cases}$$

The variation of smoke volumes with time in accordance with Equation A11.3 is shown in Figure A11.1d.

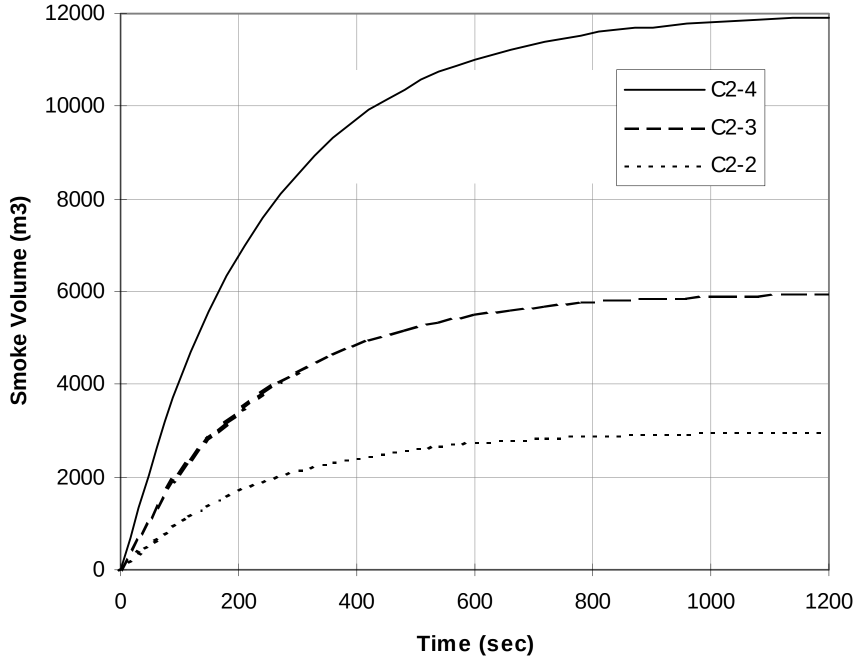

FIGURE A11.1d SMOKE VOLUME GENERATION FOR CATEGORY “C2-2”, “C2-3” AND “C2-4” FIRES

APPENDIX 12.1

DETERMINATION OF FIRE-RESISTANCE LEVELS FOR COLUMNS

APPENDIX 12.1 DETERMINATION OF FIRE-RESISTANCE LEVELS FOR COLUMNS

The temperatures of two different unprotected steel columns, when exposed to the C3 fire identified in Section 11.2.5, have been determined by heat transfer calculations. The members, which were assumed to be subject to four-sided fire exposure, have exposed surface area to mass ratios of 22.4 m^2/tonne and 7m^2/tonne, respectively. The results of the analyses are shown in Figure A12.1. It can be seen that the members reach 550°C (an estimate of the limiting steel temperature for a column) after 7.5 and 11 minutes respectively.

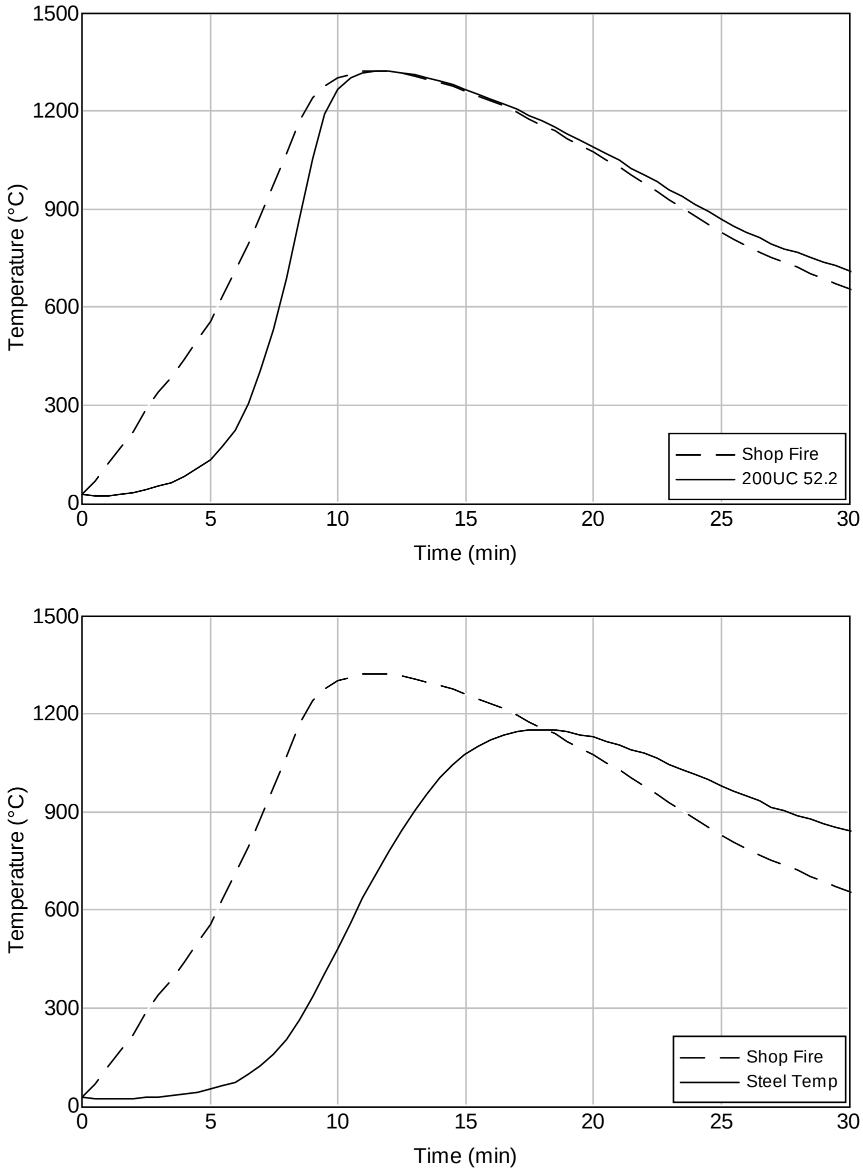

FIGURE A12.1 TEMPERATURES OF TWO UNPROTECTED STEEL COLUMNS EXPOSED TO THE C3 FIRE

Using the same computer program, the temperatures of the two members when exposed to the standard fire test heating curve, have been determined as shown in Figure A12.2. In this case it can be seen that a temperature of 550°C would be expected after 10 and 23.5 minutes, respectively. These latter times are less than those obtained from the following equation given in AS4100:

$$t = -4.7 + 0.0263T + \frac{0.213T}{k_{sm}}$$

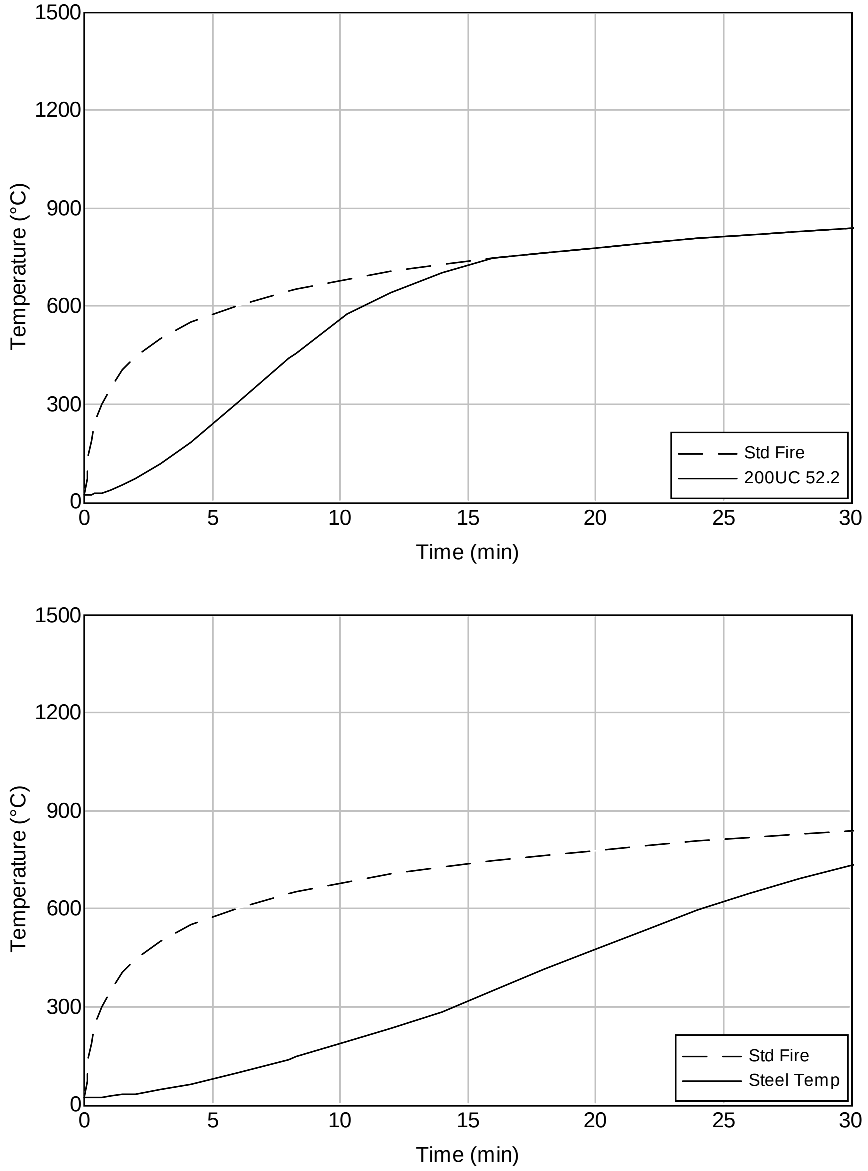

FIGURE A12.2 TEMPERATURES OF TWO UNPROTECTED STEEL COLUMNS EXPOSED TO THE STANDARD FIRE TEST HEATING CURVE

The latter equation gives times to reach 550°C as 15 and 27 minutes, for these members respectively, when subject to the standard fire test. This equation is based directly on fire test data and is considered to give the most accurate estimate of behaviour. It follows therefore that the numerical model used to estimate the time to reach 550°C is conservative in that it predicts shorter times for the members to reach 550°C.

From the above numerical analyses of member temperatures, it appears that the standard fire resistance level of a column will need to be around twice the period of time (ie. real time) that the member must survive exposure to the C3 fire.

It needs to be recognised, that because columns occur relatively infrequently, they would not be expected to be always exposed to the full effects of a C3 fire, should such a fire develop. It is more likely that the column will be partially exposed due to shielding or being located away from the centre of the fire.

APPENDIX 12.2

ADDITIONAL COMMENTS ON TYPES OF CONSTRUCTION

APPENDIX 12.2 ADDITIONAL COMMENTS ON TYPES OF CONSTRUCTION

A12.2.1 Historical Aspects

According to [46], the Australian Model Uniform Building Code AMUBC [47] required Class 6 buildings having a rise in storey of 4 to be Type 2 construction. This form of construction was described as "partially protected construction" such that the "the internal construction is not intended to survive a fire unless the fire brigade can quell it at an early stage". In practical terms this required internal beams and columns to have a fire rating of 1 hour compared with the three hours required for such elements in Type 1 construction. Buildings with a rise in storey of 3 were to be of Type 3 construction. Type 3 construction is "externally protected" such that "only the external walls are likely to survive any but a mild and short lived fire, and …. even the external walls may topple in a protracted fire". These requirements were later amended (in 1970) [45] such that four storey Class 6 buildings became Type 1 construction (the highest) and 3 storey buildings, Type 2 construction. The basis of this change is not known.

Under the AMUBC, the total floor area of buildings of Types 2-5 construction was limited unless special requirements were met including the absence of escalators and the provision of construction having a fire rating of 2 hours for the floors and for shafts surrounding stairs and lifts. In that case, each of the floors could have the limiting floor area. Sprinklers allowed the limiting floor area to be increased by 50%. It should be noted however, that the AMUBC considered that compartmentation was not required for *single storey* large isolated buildings (>20,000m^2) if sprinklers, smoke venting, roof space compartmentation, and vehicular access were provided.

In contrast to the AMUBC, the BCA (cl 2.3) allows unlimited floor areas for buildings of one or more storeys, provided it is sprinklered, has vehicular access around the building, and an adequate smoke exhaust/venting system is included.

A12.2.2 Type B Construction and "Support of Another Part"

According to Table 4 of the BCA, floors are not required to have a fire-resistance level. Internal columns, on the other hand, are required to have a fire-resistance of 180/-/-. Type B construction is a "lesser" form of construction than Type A and it is clear that the absence of requirements for floors is deliberate.

The difficulty arises in relation to the current wording of BCA (cl 2.2) [1]. According to this clause, if the floors offer lateral support to the columns (which they always will), the floors must have the same FRL. This means that the floor beams must have a fire-resistance level of 180/-/- (and slabs 180/180/180) and therefore there is no difference between Type B and Type A constructions. It should be noted that earlier versions of the BCA did not refer to the need for *lateral support* - but only to vertical support - and accordingly allowed Type B construction to be differentiated from Type A construction. This requirement for lateral support also created numerous conflicts with "concessions" for roofs, external columns etc. The above requirement for lateral support was added as an amendment to the BCA.

The performance-based BCA[2] has resolved many of the problems caused by Clause 2.2. It has restated this clause as follows:

"2.2 Fire protection for a support of another part

(a) Where a part of a building required to have an FRL depends upon direct vertical or lateral support from another part to maintain its FRL, that supporting part, subject to (b), must-
  (i) have an FRL not less than that required by other provisions of this Specification; and
  (ii) if located within the same fire compartment as the part it supports have an FRL in respect of structural adequacy the greater of that required-
    (A) for the supporting part itself; and
    (B) for the part it supports; and
  (iii) be non-combustible-
    (A) if required by other provisions of this Specification; or
    (B) if the part it supports is required to be non-combustible

(b) The following building elements need not comply with (a)(ii) and (a)(iii)(B):
  (i) An element providing lateral support to an external wall complying with Clause 5.1(b) or C1.11.
  (ii) An element providing support within a carpark and complying with Table 3.9, 4.2 or 5.2.
  (iii) A roof providing lateral support in a building-
    (A) of Type A construction if it complies with Clause 3.5(a), (b) or (c); and
    (B) of Type B and C construction
  (iv) A column providing lateral support to a wall where the column complies with Clause 2.5(a) and (b).
  (v) An element providing lateral support to a fire wall or fire-resisting wall, provided the wall is supported on both sides and failure of the element on one side does not affect the fire performance of the wall."

It will be noted that this clause explicitly states that it does not apply to situations where other clauses allow certain elements not to have an FRL - eg. a roof in a building of Type B construction. The wording of the clause also makes it clear that members providing vertical or lateral support to another member within a fire compartment must have the same fire-resistance level as the supported member, if such support is necessary for the supported member to achieve its fire-resistance level.

If the floors of a Type B building do not have a fire-resistance level then the building must presumably be considered as one compartment. Thus all floors (beams and slabs) must have an FRL of the same value, if their presence is necessary for the column to achieve the FRL. Alternatively, one could design the columns in the building as "cantilever" members that require no lateral support from the floors. The effect of this would be that the columns would remain upright with no attached floors when subject to a fire equal in severity to a standard fire of 180 minutes, whilst the floors would have failed very much earlier. It must be asked - is this a sensible requirement?

It would appear that the basis of the requirement in Table 4 is centred on the *valid* principle that columns are more significant members than beams. That is, failure of a floor or beam has immediate significance only for the part of the floor concerned, whereas failure of a column can have an impact on the levels above. However, there is little sense in the columns being required to have a fire-resistance of 180 minutes.

APPENDIX 14.1

VEHICULAR ACCESS

APPENDIX 14.1 VEHICULAR ACCESS

It is believed that the vehicular access requirements of Clause C2.4 of the BCA originated from early regulations relating to large area/volume single storey buildings - as might be encountered with a large warehouse building. The vehicular access required by C2.4 is there for the purpose of assisting the fire brigade in fighting a large fire from *any* position around the *outside* of the building. The restriction of the distance from the outer edge of the roadway to the wall of the building to 18m would appear to be related to the positioning of a fire truck and the ability to deliver water from the relative safety of the truck.

In the context of a shopping centre it is difficult to see the value of the above requirement for the following reasons:

i. As shown in this report, the probability of having a fire that can only be handled from outside the building is extremely small.

ii. If the fire has got to a size that it has to be fought from outside the building, then it is an extremely large fire; and it is questionable whether the fire brigade will be able to have much impact due to the fact that the heat generated by the fire will greatly outweigh the energy absorbing capacity of the water being delivered to the fire. Therefore, there would appear to be little value in this activity[53].

iii. The above requirement has nothing to do with minimizing spread between buildings as this is covered by the minimum distance to fire-source features and external wall requirements given in the BCA.

iv. Occupants will have left the building before the fire gets to the stage that it can only be fought from outside. Therefore life safety is not an issue

One other possible reason for C2.4 relates to allowing access for the fire brigade *into* any part of the building from the outside of the building. In relation to a shopping centre, access into the building can be achieved via the *normal* exits (and entrances) and it is important that ready access to these locations is provided for vehicles - but this can be achieved without requiring continuous vehicular access around the building. In theory, it is also possible to gain access through the emergency exits but this is most unlikely for the following reasons:

i. Advice from the fire brigade which suggests that use of these exits for fire-fighting purposes would be rare and only after detailed knowledge of the fire and the building were obtained.

ii. The exits are locked from the outside for security reasons and entrance requires smashing of a lock. This can be done but will not be a first choice action. In any case, *vehicular* access around the building is not necessary to allow fire brigade access through these emergency exits.

Continuous vehicular access around the building does, in theory, reduce the time required to drive from one entrance to another, should it be realised that the fire needs to be approached from a closer entrance. However, if guidance as to the

[53] The severity of the fire will reduce as the fuel in that part of the building is consumed.

correct entrance is available to the fire brigade before they arrive at the building, the response time will be reduced and there will be little need for continuous access. This can be achieved through the provision of FIP panels at each of the entrances, with each panel monitoring only the part of the building closest to that entrance. Activation of a detector or sprinkler will result in an alarm to the fire brigade which will indicate the part of the building in which the alarm has occurred. This, in turn, will allow the brigade to make their way to the appropriate entrance.

In summary, it is concluded that there is little basis for the current vehicular access requirements of C2.4. What is required is adequate vehicular access to nominated major entrances from which fire brigade activities can be launched and more specific guidance for the fire brigade.

APPENDIX 14.2

HOSE LINE WATER SUPPLY CHARACTERISTICS

APPENDIX 14.2 HOSE LINE WATER SUPPLY CHARACTERISTICS

The following water can be supplied typically from appliance hose reels and hose lines:

Appliance Equip	*Nozzle Size (mm)*	*Nozzle Pressure (kPa)*	*Discharge (l/min)*
25 mm high pressure hose reel		2500	200
38 mm hoses	9	200	80
	12.5	300	150
	16	400	350
38 mm Turbojet	Setting No. 30	700	114
	Setting No. 60	700	227
	Setting No. 95	700	360
	Setting No. 125	700	473
65 mm hose	12.5	300	150
	16	400	350
	19	500	950
	22	600	800
	25	700	1150

APPENDIX 14.3

EVALUATION OF FIRE-FIGHTING CAPACITY

APPENDIX 14.3 EVALUATION OF FIRE-FIGHTING CAPACITY

The major mechanism of fire spread from one shop to another will be via the ceiling void after collapse of the ceiling. As a rough guide, tiled ceilings will collapse 1—10 minutes after flashover, whereas plasterboard will survive for around 20 minutes. The storage areas of some specialty shops (about 5%) do not have a ceiling in order to maximise the storage height; and in this case there is direct access into the ceiling space. Flames entering the ceiling space of the shop next door will heat the hanger support system and result in expansion of the system and dislodgment of the tiles. Again, a plasterboard system will perform considerably better. Assuming that a ceiling has collapsed and that the flame temperatures are 850°C, a horizontal radiation panel emitting 81 kW/m^2 to the combustibles can be assumed (see Figure A14.3.1).

If it is considered that the combustibles may be exposed to a radiation of 10 kW/m^2 without ignition occurring (assuming no direct flame impingement), then it follows that water must be applied into the room to absorb the (81-10) kW/m^2. However the application of water into the room will not be uniform due to the fact that it is being applied by means of a hose stream as opposed to a uniform spray and an inefficiency factor of between 2-3 (take 2.5) is adopted to allow for this effect. The plan area of the specialty shop is taken as 100m^2. The heat of vapourisation of water is 2.26 x 10^6 kJ/m^3. It follows that the volume flow rate of water that must be applied to prevent spread is:

$$\frac{71\times10^3\times2.5\times1000\times60\times100}{2.26\times10^9} = 471 \text{ litres per minute.}$$

APPENDIX 14.4

FIRE SPREAD ACROSS MALL

APPENDIX 14.4 FIRE SPREAD ACROSS MALL

The likelihood of fire in a specialty shop spreading across the mall is assessed. For the purpose of this analysis, the criteria for normal ignition range is taken as 20 kW/m² [3]

The average frontal width of a specialty shop is 7.2 m. Assuming that the floor-to-floor height is 5 m, the radiating panel is therefore 7.2 m × 5 m. The level of radiation flux on a specialty shop across the mall is given by the expression [3]:

$$q_r = \phi \sigma \varepsilon T_f^4$$

where q_r = heat flux kW

ϕ = configuration factor

σ = Stefan-Boltzmann constant (5.67×10^{-11} kW m^{-2} K^{4})

ε = emissivity (~ 1)

Assuming a typical mall width of 12 m, the configuration factor is calculated to be 0.073 [3]. At its peak, the flame temperatures approaches 1300 K. The imposed radiant heat flux on the surface of an adjacent specialty shop is therefore

$$q_r = 0.073 \times 5.67 \times 10^{-11} \times 1 \times 1300^4$$
$$= 11.8 \text{ kW}$$

It is unlikely that spread would occur at this level.

However, when the fire has spread across to the immediately adjacent enclosures, the radiation level from the three specialty shops combined (ϕ = 0.159) are calculated as follows:

$$q_{r3} = 0.159 \times 5.67 \times 10^{-11} \times 1 \times 1300^4$$
$$= 25.7 \text{ kW}$$

It is likely that spread would occur at this level.