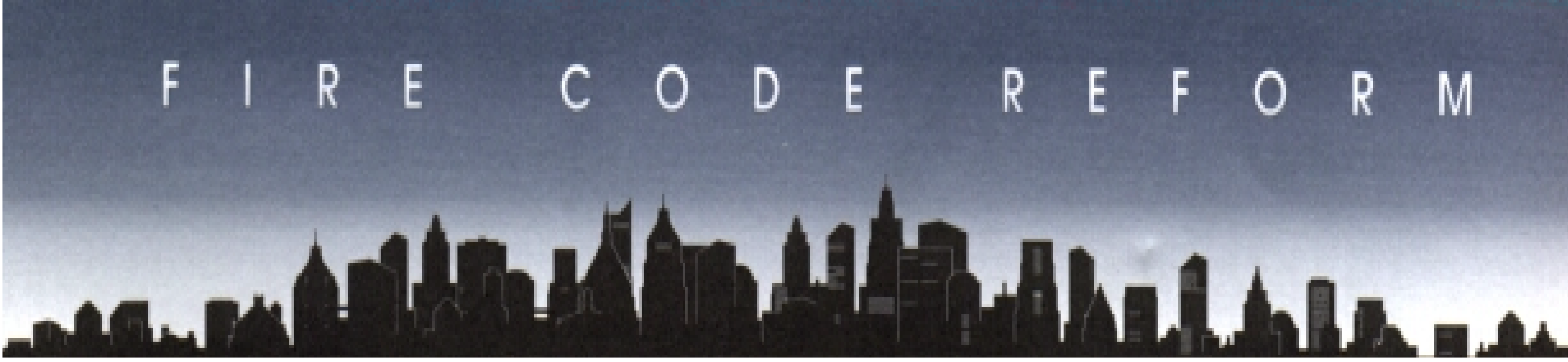

Project Report
FCRC PR 00-02

Fire Safety in Shopping Centres

Effect of Combustible Construction on Fire Safety in Shopping Centres.

FCRC Project 6 Supplement
Fire Safety in Shopping Centres

Fire Code Research Reform Program
February 2000

Important Notice

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Comments

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THE EFFECT OF COMBUSTIBLE CONSTRUCTION ON FIRE SAFETY IN SHOPPING CENTRES

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EXECUTIVE SUMMARY

The Project 6 Report, *Fire Safety in Shopping Centres* (Final Research Report, Project 6, Fire Code Reform Centre, July 1998) is a guide for the specific fire engineering design of sprinklered shopping centres of non-combustible construction.

This report reviews the Project 6 Report and investigates its applicability to types of construction that use combustible building materials, including wood-based lining materials on the walls and ceilings, and heavy structural timber and light timber frame construction for the building structure. This report does not consider plastic materials.

The conclusions of this report are based on the expected behaviour of the building and the occupants in the unlikely event that a fire occurs when the sprinkler system is not operative. If sprinklers could be considered 100% effective, there would be no reason to limit the type of building materials, and no reason to have fire resistance levels for any part of the structure, but sprinklers do not always operate as expected. The Project 6 Report states 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.'

If a fire occurs when the sprinklers are not operative, an uncontrolled fire could occur, and the design objective is to ensure life safety, but no property protection.

RECOMMENDATIONS

The following are the main recommendations made in this report:

- The Project 6 Report should be developed into a design guide that includes wood-based building materials on an equal footing with steel and concrete.
- Major improvements suggested for the Project 6 Report include the following:
    - A fire detection and alarm system should be provided in the mall, large shop and unoccupied areas, in addition to the automatic sprinkler system. Occupants, initially remote from the fire, require a cue other than dense smoke to initiate evacuation.
    - The relationship between the Project 6 Report and other documents such as the Building Code of Australia should be clarified.
    - The safety of shopping centres with roof or basement carparks should be addressed explicitly.

CONCLUSIONS

The conclusions of this report are that:

- Timber should be permitted as a structural material on an equal footing with steel and concrete, provided that the fire resistance levels are adequately defined.
- Wood-based lining materials should be permitted in certain limited areas of shopping centres.

Lining materials:

- Wood-based panel materials should not be permitted as linings on ceilings, in order to reduce the possibility of rapid spread of fire. The hot gases from a fire collect in a hot upper layer below the ceiling, preheating the ceiling material, so that the presence of wood-based lining materials in this region can enhance the rapid spread of fire. Wood-based lining materials on walls can contribute to vertical fire spread, and can enhance radiation to exposed fuel items. For these reasons, wood-based lining materials should not be permitted on the walls in exitways or fire-isolated stairs. Smaller areas of wood, such as exposed timber beams and columns, are acceptable throughout.

Structural and containment elements:

- The required fire resistance levels for all structural members and containment elements should be independent of the construction materials. Wood based materials, including heavy timber construction and light timber frame construction should be permitted throughout.
- Whatever the building materials, the fire resistance levels for the structure and for the containment elements should exceed the time required for all occupants to escape from the building. The calculated evacuation time must include the time for detection, the sounding of the alarm, occupant decision making, investigation and first aid fire fighting, queuing time, travel time and a safety factor. This should include the time required to evacuate the carparks unless they are separated by additional fire-rated construction.
- The minimum level of fire resistance provided by the structure and the containment elements should be 30 minutes, regardless of the building materials. Fire Resistance Levels below 30 minutes are not meaningful, as the standard fire resistance test was not designed to test for such short periods. No fire resistance is necessary for the roof or elements supporting the roof.
- The containment elements required to slow down the spread of fire, to give the occupants sufficient time to evacuate to safety, as required by the Project 6 Report, are:
    - Floors, but not the roof,
    - Walls to fire-isolated stairs,
    - Walls separating the carpark from the rest of the shopping centre,
    - Ceiling barriers at 50 m centres or every 10th shop, whichever is less, where there are no combustibles in the ceiling cavity.
- Additional requirements for containment elements are recommended as follows:
    - Ceiling cavity barriers should be provided at the boundary between all shops (specialty shops and department stores) and the mall and between the specialty shops and the department stores.
    - Ceiling cavity barriers should be provided to the periphery of local areas which contain no ceiling.
    - The ceiling barriers should be of protected lightweight construction, eg. plasterboard linings on steel or timber studs. Any gaps around service penetrations through the ceiling barriers should be filled with a non-combustible material.
    - Where the ceiling cavity contains exposed timber, fire rated ceiling cavity barriers should be provided at 25 m centres or at every 5th shop, whichever is less and all ceiling cavity barriers should be fire rated.

- For timber floor assemblies relying on a ceiling membrane to provide fire resistance, it is suggested that the fire resisting membrane be attached directly to the underside of the floor structure and an additional suspended ceiling be provided in the shops. This allows recessed light fittings and building services to be placed in or on the suspended ceiling without penetrating the fire resisting membrane, and eliminates timber surfaces in the ceiling cavity.

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1 INTRODUCTION

1.1 Scope

The Project 6 Report, *Fire Safety in Shopping Centres* (Final Research Report, Project 6, Fire Code Reform Centre, July 1998)[1] is a guide for the specific engineering design of sprinklered shopping centres of non-combustible construction. This report reviews the document and investigates its applicability to types of construction that include combustible building materials. The combustible building materials include wood-based lining materials on the walls and ceilings, and heavy structural timber and light timber construction. This report does not consider plastic materials for structural members or linings.

1.2 Background

There was a belief that some of the regulatory requirements in the Building Code of Australia (BCA)[2,3] for large shopping centres were unnecessarily onerous, and were imposing financial burdens on developers and owners. The Project 6 Report, *Fire Safety in Shopping Centres* was the result of a study undertaken to provide a more rationally-based set of fire requirements which would improve the cost effectiveness of these buildings in terms of both construction costs and maintenance in operation, whilst maintaining the current high levels of fire safety.

The Project 6 Report applies to low-rise sprinklered shopping centre buildings which have a rise in storey of up to four and which are constructed from non-combustible materials. The Project 6 Report contains no recommendations for the use of combustible materials. This document investigates the applicability of The Project 6 Report to types of construction that include timber materials.

1.3 Layout of this Report

An interpretation of the Project 6 Report, including a summary, its objectives, the type of building and construction materials to which it applies, its purpose and a summary of its inconsistencies are given in Section 2.

Section 3 addresses the requirements for wood-based lining materials. It includes a summary of the proposed requirements from the Project 6 Report, a review of the fire incidents in retail premises that relate to combustible finishes, and a discussion and recommendation for the requirements for the wood-based lining materials on the ceilings and walls.

Section 4 outlines the objectives and requirements for the fire resistance of containment elements and structure. It includes a summary of the proposed requirements from the Project 6 Report and a review of fire incidents in retail premises which were constructed with combustible materials, had rapid fire spread, or where the fire-rated construction failed.

Section 5 contains an outline of the fire resistance of timber materials, including heavy timber structures and light timber framed structures. It includes the fire behaviour and the calculation of the fire resistance levels for structural members in timber construction.

The conclusions are given in Section 6.

Appendix A is a chapter by chapter review of the Project 6 Report. The review is presented in tabular form with the summary of the Project 6 Report and comments in separate columns. The comments relate to the objectives of the Project 6 Report, also covering inconsistencies and the impacts of combustible finishes and combustible structure.

Appendix B contains a review of the fires from *Case Studies of Fires in Retail Buildings*[4] which occurred in buildings with combustible surface finishes, that were constructed with combustible materials, had rapid fire spread, or where the fire-rated construction failed.

2 INTERPRETATION OF THE PROJECT 6 REPORT *Fire Safety in Shopping Centres*

This section contains a summary of and comments on the objectives, type of building and construction materials and purpose of the Project 6 Report, *Fire Safety in Shopping Centres*[1]. (The figures in brackets are clause numbers from the Project 6 Report.)

2.1 Summary

The remit of Fire Code Reform Centre Project 6 was 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 would 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 Project 6 Report reviews the current BCA requirements and identifies the key issues for consideration due to cost or safety concerns. Life safety and property protection are considered. It includes the history and apparent lessons made from a review of 97 fires in retail buildings detailed in the report *Case Studies of Fires in Retail Buildings*[4] . The key findings are identified from a statistical study of retail fires in the USA, detailed in the report *Analysis of US Retail Fires*[5]. Survey information is included from eleven shopping centres in Australia. The details of the survey are in the report *Shopping Centre Review*[6]. A summary is given of eleven full-scale fire tests which were conducted to investigate the effects of fires in specialty shops and major stores. *Simulated Shopping Centre Fire Tests*[7] reports in detail on the fire tests. The reliability and efficacy of sprinklers is reported on, including how to make the sprinklers more reliable.

The Project 6 Report gives a description of the relevant fire scenarios, their broad characteristics, their likelihood of occurrence and their potential impact on the occupants and the building. The fires are grouped into 3 classes: C1 - fires which are kept small without the presence of sprinklers; C2 – fires controlled by the presence of sprinklers; and C3 – fires which are not limited to the area of fire origin. The shopping centre occupants' response to fire cues and their movement is discussed. Calculation methods for the time for movement to a safe place are given.

The Project 6 Report outlines the objectives for smoke management and 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. It considers the role of the building structure in providing fire safety and determines the fire resistance levels required for the various parts of the building, taking into account the range of fire scenarios. The impact of the fire brigade on the various fire scenarios, and conversely, the effect of these fire scenarios on the brigade are discussed.

2.2 Objectives

The objectives of design in accordance with the Project 6 Report, *Fire Safety in Shopping Centres*, are not stated explicitly. In order to recommend changes to the Project 6 Report for wood-based materials, it has been necessary to determine the implied objectives, and the outcomes of design in accordance with the report.

The Project 6 Report is based on three fire scenarios. The following are the implied outcomes of the various fire scenarios:

C1 fire (fire confined to item first ignited)

No threat to life safety.
No alarm or evacuation.
No damage to property except minor damage in immediate locality of the fire.

C2 fire (fire controlled by sprinklers)

The fire is detected by the sprinkler system.
The alarm sounds and the occupants evacuate the building.
The smoke management system keeps the smoke layer high.
The occupants are considered to be safe when they reach the mall, or an enclosed stairwell, or a ventilated carpark.
Minor fire damage and water damage occurs in vicinity of the fire
There is significant smoke damage remote from the fire.

C3 fire (flashover fire resulting from sprinkler failure)

No alarm sounds.
The fire is seen by nearby occupants who alert others.
The occupants in other parts of the building are possibly alerted by thermal movement of the floor and/or dense smoke. (12.2.5.2.2(i))
Those occupants who know about the fire evacuate the building.
The mall is not a safe place, so evacuation must be to lower floors and to outside the building.
The fire spreads to adjacent shops and upper floors.
The building is partially or totally destroyed, depending on Fire Brigade response.
Fire damage, smoke damage and water damage occur throughout the remaining building.

The objectives for a C1 and C2 fire are life safety and property protection. The objective for a C3 fire is life safety only. The relative levels of life safety and property protection provided in the event of a C1, C2 or C3 fire is as shown in Table 1.

Fire Scenario	Life Safety	Property Protection
C1	***	***
C2	**	**
C3	*	-

*** Very high level of protection
** High level of protection
* Marginal level of protection
- No protection

TABLE 1: Levels of fire protection for various fire scenarios, as implied by the Project 6 Report

2.3 Types of Buildings & Construction materials

The Project 6 Report, *Fire Safety in Shopping Centres* applies to low-rise sprinklered shopping centres that meet all of the following criteria:

- The rise in storey is no more than four. (1.1)
- The building is fully sprinklered in accordance with AS 2118, including carparks. (1.1, 11.4.2.2)
- The building contains a covered walkway or mall. (1.1)
- The building does not contain occupancies other than the following classes (BCA terminology):

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. (1.1)

- The report does not apply to 'warehouse' buildings where goods are stored in racks above four metres and sprinklers are located only at roof height. (1.1)
- The levels within the shopping centre are interconnected by means of escalators or travelators located within the mall. (Chapter 9)
- The walls between the shops are protected lightweight construction, incorporating combustible or non-combustible framing eg. plasterboard linings on either side of a steel or timber stud. (13.4.3, Chapter 16)
- Materials of construction 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) are to be non-combustible. (16.2)

The Project 6 Report makes no reference to shopping centres with roof or basement carparks. In the event of a fire in a shopping centre with a roof or basement carpark, many of the occupants will move towards their vehicles. The presence of a roof or basement carpark will alter the behaviour of the occupants and thus the fire resistance and smoke management requirements. eg. in the event of a C3 fire in a shopping centre with a roof carpark, the fire resistance rating for the structure must be sufficient to allow time for the occupants to move to the roof and exit the building, in their cars, from that level.

The Project 6 Report does not include any requirements for the protection of adjacent properties, so it can only be used where there are large separation distances. If adjacent properties are close to the shopping centre, then additional containment and structural fire resistance levels may be necessary to prevent a C3 fire from spreading as a result of radiation from window openings or structural collapse.

Offices and cinemas are areas that can be closed off from the general mall area, away from the general public. Occupants of these spaces would not receive the same notification of the occurrence of a fire, from dense smoke or the observance of other occupants evacuating. It appears that the Project Report 6 does not cover this type of building arrangement.

2.4 Purpose of the Project 6 Report

The Project 6 Report makes a valuable contribution to fire engineering design of shopping centres by attempting to put together a comprehensive performance based design philosophy, including conventional active and passive fire protection and other less conventional measures such as fire fighting by occupants and special management of sprinkler maintenance.

Unfortunately the actual purpose of the Project 6 Report is not very clear. The purpose is difficult to assess because it includes a mixture of the following items with no guidance as to how they are to be used:

1. Survey of fire safety in existing shopping centres.
2. Investigations on possible fire growth, smoke movement and occupant behaviour in shopping centre fires.
3. Prescriptive requirements for the construction of shopping centres.
4. Guidelines for performance based design of shopping centres.

Items 1 and 2 provide a wealth of useful information that will be helpful for any designers of shopping centres, whether they are using prescriptive rules or performance based design.

With regard to Item 3, some prescriptive or semi-prescriptive recommendations are given, including:

- Sprinkler layout and management (Chapter 7)
- Fire Resistance Levels, FRL (12.5)
- Stair width, location and spacing (11.4.2.1)
- Materials of construction: Ceiling barriers (13.4.3)

Many of these reappear with even stronger recommendations in the Conclusions (Chapter 16), which is repeated in the Executive Summary.

With regard to Item 4, some guidance is given for performance based design, including:

- Smoke management calculations (11.5, 11.6)
- Design for evacuation (Chap 10, 11.4)

The Project 6 Report cannot be used as a stand-alone design guide because it does not give sufficient performance criteria and they are mixed up with prescriptive recommendations.

The Project 6 Report contains many relaxations from the Building Code of Australia, which are considered to provide sufficient safety if they are all implemented as part of a coherent integrated design. There is a danger that some casual users of the Project 6 Report could use it to justify isolated departures from the Building Code of Australia without recognising the inter-related nature of the Project 6 recommendations. This should be highlighted in any future revisions.

2.5 Limitations and Inconsistencies

The Project 6 Report contains a number of limitations and internal inconsistencies including the following:

- The relationship between the Project 6 Report and other documents such as the Building Code of Australia is not clear. The Project 6 Report is not sufficiently complete to be used as a stand-alone document, but it is not clear whether the Building Code of Australia or various standards for active fire protection should be used where there is missing information.

- Various assumptions about surveyed shopping centres are used in the design guidelines, but they are not stated in the report. For example, there are no limitations on the size or shape or layout of the shopping centre, yet the case studies in the report are all for a particular style of design. There are such a large number of possible layouts for shopping centres up to four storeys high, that each case must be considered as a separate design.

- The Project 6 Report states that dense smoke will initiate movement. However, it is likely that there will be areas of the building, initially remote from the fire, which will not 'see' the dense smoke from the C3 fire until the fire has developed significantly, giving the potential for the occupants to be trapped or overcome by the fire. The Project 6 Report does not adequately explain how occupants will be alerted to a C3 fire if the sprinklers do not work.

- The treatment of C3 fires (flashover fires resulting from sprinkler failure) is inadequate and inconsistent. The C3 design fire, used for the design of the smoke management systems and for the calculation of the egress times on which the structural Fire Resistance Levels are based, is derived from an experiment with a isolated shop in which the fire burns out. In the Project 6 Report it states that if a C3 fire has spread beyond the room of origin, it would be difficult for the fire brigade to have much impact, the radiation from the C3 fire would prevent the fire brigade from getting close to the fire. ie. the fire does not burn out and reduce in size. The Project 6 Report considers that fire can spread beyond the room of origin, in which case the mall is unlikely to remain a safe place. The Project 6 report states that the smoke extract system should be designed for a C3 fire but points out that an exhaust system is unlikely to cope with the quantity or temperature of the smoke.

- A Fire Resistance Level, FRL, of 15 minutes is specified. 15 minutes is not a meaningful FRL, as the standard fire resistance test was not designed to test for such a short period. A minimum FRL of 30 minutes should be specified, for reasons outlined in Section 4.5.

- Fire Resistance Levels are too low. The prescribed FRLs are intended to provide sufficient time for the occupants to escape. The time at which the occupants commence evacuation and from which the fire resistance is measured is the time when dense smoke is first seen. There may be areas, remote from the fire, where occupants will not see any smoke and the initiation of evacuation will be delayed, resulting in a greater egress time and the requirement for greater FRLs.

- Gaps around penetrations in the ceiling barriers of up to 50 mm are permitted in the Project 6 Report. Gaps of this size could provide a means for the fire to spread through the ceiling barriers.

- Reduced occupant loads are based on a detailed survey of only one shopping centre assuming an average length of stay of 2 hours in the centre. If the average stay was 3 hours, then the occupant numbers would go up by over 50%.

- The objective of property protection is not dealt with consistently. The introduction to the report states that property protection needs to be considered, but there appears to be exceptions. For example, the Project 6 Report makes no attempt to control the extent of the smoke damage in the event of a C2 fire.

- The Project 6 Report states that sprinklers will not be effective at heights greater than 10m above the closest floor level. It recommends that other strategies be developed for handling fires within malls and atrium spaces. The Project 6 Report does not discuss the alternative strategies for the mall and atrium spaces or the effect of the systems in these areas on the shopping centre as a whole. Alternative means of controlling a fire in an atrium or mall will generate specific requirements for the smoke management system, for the control of fire spread and for the fire resistance of the structure.

- An integrated design of the smoke management system is required for the building as a whole. For example, the smoke extract system in the atrium, if operated in the event of a C2 fire elsewhere in the building, could cause smoke to be dragged into the mall which is supposed to be a safe place.

- An expression for smoke volume is derived for a C2 fire and it is stated that it is based on very limited data and should be used with caution. No alternative means of calculating smoke volumes is given.

3 WOOD-BASED LINING MATERIALS

This chapter investigates the effect of wood-based lining materials on the requirements for fire safety in shopping centres.

The chapter is divided as follows:

- Section 3.1 summarises the requirements for finishes proposed by the Project 6 Report,
- Section 3.2 reviews the fire incidents in retail premises with combustible finishes from the report *Case Studies of Fires in Retail Buildings*[4],
- Section 3.3 calculates the additional fire load contributed by the wood-based lining materials,
- Section 3.4 outlines the effect of wood-based lining materials on walls,
- Section 3.5 outlines the effect of wood-based lining materials on ceilings,
- Section 3.6 summarises the requirements for the use of wood-based lining materials in shopping centres.

The objective, with respect to lining materials, is to prevent rapid fire growth and spread. Rapid fire growth and spread will reduce the egress time available to the occupants. Life safety is the issue to be considered.

3.1 The Project 6 Report Proposed Requirements for Finishes

The requirements for finishes from the Project 6 Report are

> '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.' (16.2)

The general requirements of BCA Clause C1.10 [3] for lining materials are:

- Any material used in a Class 5,6,7, or 9b building (ie. in a shopping centre) must have a Spread-of-Flame Index of not more than 9; and a Smoke-Developed Index of not more than 8, if the Spread-of-Flame Index is more than 5. As an example, untreated uncoated plywood has a Spread-of-Flame Index of 7 and a Smoke-Developed Index of 3 [8], therefore wood based lining materials are permitted.
- In a fire-isolated exit, materials must have a Spread-of-Flame Index of 0, a Smoke-Developed Index of not more than 2; and if combustible, be attached directly to a non-combustible substrate and not exceed 1 mm in finished thickness. Therefore wood-based lining materials are not permitted in fire-isolated exits.
- In a Class 9b building, in a public corridor which is a means of egress to a fire-isolated exit or external stair used instead, any lining material must have a Spread-of-Flame Index of 0 and a Smoke-Developed Index of not more than 5. Therefore wood-based lining materials are not permitted in these areas.

The Project 6 Report also states

> '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).' (16.2)

These recommendations for surface finishes are supported in this study.

3.2 Fire Incidents in Retail Premises

The report *Case Studies of Fires in Retail Buildings*[4] reviews and documents the fatalities in 97 fires in retail buildings. The report has been reviewed and the fires from this report that occurred in buildings with combustible surface finishes are listed in Appendix B. Fires which occurred in buildings that were constructed with combustible materials, had rapid fire spread, or where the fire-rated construction failed (ie. it collapsed or the fire spread) are also listed in Appendix B.

A summary of the lessons from the case studies with respect to surface finishes is:

- Fires occurred in three shopping centres where the large fuel load was such that the fire spread rapidly irrespective of the surface finishes or construction materials. There was no compartmentation in these shopping centres and deaths occurred in two of these fires.
- Combustible ceilings can lead to the rapid spread of fire. Combustible ceilings contributed to the rapid fire spread in the fire in L'Innovation in Belgium where 400 people were killed.
- Non-compartmented, unsprinklered ceiling spaces can be a major cause of rapid smoke and fire spread. Combustible surface finishes and combustibles in the ceiling space exacerbate this.
- In one fire, flashover occurred across combustible ceiling tiles and resulted in rapid fire spread from the front to the back of the building, killing 3 fire fighters.
- In one fire, sprinklers prevented the spread of fire to a combustible ceiling.
- There was a case where fire spread up an external wall clad in timber shingles to an unsprinklered walkway and 80% of the timber walkway was destroyed.

3.3 Additional Fire Load from Wood-Based Lining Materials

Shops typically have a high fuel load due to the nature of the contents, including the goods for sale, the shop fittings and the floor coverings. The survey of combustibles in a shopping centre in Australia, detailed in the report *Shopping Centre Review*[6], showed that the fire load density (wood equivalent) for the specialty shops was up to 180 kg/m^2. For an average shop area of 100 m^2 this equates to 18,000 kg of wood or a fire load energy of 288,000 MJ, assuming a heat of combustion of 16 MJ/kg for wood.

Cladding the ceiling of the 100m^2 shop with 12 mm plywood or customwood would add approximately 8640 MJ to the fire load energy. This is a 3 % increase in fire load energy, therefore the contribution of wood-based ceiling lining materials to the fire load in the shops is not significant.

Cladding the walls of the 100m^2 shop with 12 mm plywood or customwood would, assuming a 10 m by 10 m shop with a 3.6 m ceiling height, add approximately 9330 MJ to the fire load energy. This is a 3.2 % increase in fire load energy, therefore the contribution of wood-based wall lining materials to the fire load in the shops is not significant.

Therefore, the contribution of the wood-based lining materials, on the walls and ceiling, to the fire load in the shops is not significant. Combustible surface finishes, however, can contribute significantly to the rapid growth and spread of fire.

3.4 Wood-Based Lining Materials on Ceilings

In the event of a C1 fire, the fire is limited to the area of fire origin by means of self-extinguishment or occupant and/or fire brigade intervention, without the assistance of sprinklers. The fire does not spread from the objects of origin, and does not produce sufficient hot gases to form a hot upper layer of gases which could cause the lining materials on the ceiling to ignite. Therefore the presence of the wood-based ceiling lining materials will have no effect on the fire growth and spread.

In a C2 fire, the sprinklers are activated and control the fire. Once the sprinklers have activated, the temperature of the fire and the upper hot layer of gases are reduced such that lining materials on the ceiling will not ignite. Ignition of the ceiling linings before the sprinklers are activated could lead to rapid fire spread above the sprinklers and the potential for the sprinklers to be overwhelmed. Pendant-type sprinklers typically do not spray water directly onto the ceiling and therefore will not be effective in controlling a ceiling fire. The potential for the ignition of the ceiling lining is significant for combustible finishes such as foam or plastics, however these finishes are outside the scope of this report. It is less likely that a ceiling of wood based products will ignite before the sprinklers are activated.

In an uncontrolled, C3, fire, the review of the case studies shows that the presence of wood-based lining materials on the ceiling can contribute significantly to the rapid spread of fire. The hot gases from the fire collect in a hot upper layer below the ceiling, preheating the ceiling, and this leads to the rapid spread of the fire. Combustible ceilings contributed to the rapid fire spread in the fire in L'Innovation in Belgium where 400 people were killed. In another fire, flashover occurred across combustible ceiling tiles and resulted in rapid fire spread from the front to the back of the building, killing 3 fire fighters.

In summary, to prevent the rapid spread of fire, ceilings of wood-based lining materials should not be permitted.

3.5 Wood-Based Lining Materials on Walls

No large-scale fire tests of lining materials are known of. Standard room fire tests of common wall linings with a gypsum lined ceiling have shown that the time to flashover of untreated plywood was less than 10 minutes, whereas that of fire-retardant treated materials was greater than 10 minutes. In tests with gypsum board wall linings flashover did not occur. [9,10,11] These test results show that the wall lining material does effect the time to flashover, however in a shopping centre the effect of the combustibles in the shop must also be considered.

In the event of a C1 fire, the fire is limited to the area of fire origin by means of self-extinguishment or occupant and/or fire brigade intervention, without the assistance of sprinklers, therefore the presence of wood-based wall lining materials will have no effect on the fire growth and spread.

In a C2 fire, the sprinklers control the fire. The wood-based lining material on the walls may be the object on which the fire originates, or the fire may spread to the wall from the shop contents or fittings, but the sprinklers will be activated and will control the fire. Wood-based wall lining materials may mean faster fire spread and earlier activation, but there is no significant effect on life safety or property protection.

In the event of a C3 fire, the sprinklers do not activate. The wood-based linings on the lower part of the walls will not contribute to the spread of the fire much more than the combustible contents of the shops, although a fire in a corner of a shop may be subjected to radiative enhancement from the combustible wall linings. The extra contribution to the fire load is not significant in the shops, as outlined in Section 3.3. In the mall, the contribution of the wood-based wall lining materials to the fire load will be more significant, however, as stated in the Project 6 Report, it is unlikely that a fire will go undetected and develop into a C3 fire in the mall area. Combustible linings on the upper walls can contribute to rapid vertical flame spread. The upper portion of the wall will be in the hot upper layer of gases and subject to radiation from the hot gases and from the ceiling. Preheating of wood-based lining materials could contribute to the spread of fire along the upper portion of the walls. Spread along the wall is not as significant as the spread across the ceiling, therefore it is recommended that wood-based lining materials be permitted on the walls of the shops and in the mall.

Wood-based lining materials should not be permitted on the walls in fire-isolated stairs, in exitways or in the mall, to minimise the rate of fire spread in these egress routes.

In summary, it is recommended that wood-based lining materials on the walls should not be permitted in the fire-isolated stairs, in exitways or in the mall, but should be permitted elsewhere.

3.6 Requirements for Wood-Based Lining Materials

The lining materials on the ceiling are within, and preheated by, the hot upper layer of gases. If the lining materials are wood-based, this may lead to the rapid spread of the fire. Therefore large areas of wood-based lining materials on the ceiling should not be permitted.

There should no restriction on the presence of wood-based lining materials on the walls in the shops. The lining materials will not contribute significantly to the rapid spread of fire, due to the high fire load of the shop contents and fittings adjacent to the wall.

Wood-based lining materials should not be permitted in fire-isolated stairs and exitways or in the mall.

Exposed timber beams and columns, due to their limited size and extent will not contribute significantly to the spread of fire, and are acceptable.

The limitations on wood-based lining materials could be relaxed if suitable fire-retardant treated materials are used.

These recommendations apply to the lining materials regardless of the structural materials used in the building.

The combustibility of the ceiling materials is considered further in Section 4.3, Containment Structures.

4 FIRE RESISTANCE OF CONTAINMENT ELEMENTS AND STRUCTURE

This chapter investigates the requirements for the fire resistance of the containment elements and the structure. Containment elements slow down the spread of fire, giving greater time for the occupants to evacuate to safety. The fire resistance of the structure ensures that the structure remains in place for sufficient time to allow the occupants to evacuate to a safe place.

The chapter is divided as follows:

- Section 4.1 summarises the requirements for the fire resistance of containment elements and structure proposed by the Project 6 Report,
- Section 4.2 reviews the fire incidents in retail premises, from the report *Case Studies of Fires in Retail Buildings*[4], in which the buildings were constructed of timber, had rapid fire spread or where the fire-rated construction failed,
- Section 4.3 discusses the requirements for containment elements in shopping centres,
- Section 4.4 discusses the requirements for the fire resistance levels of the structure,
- Section 4.5 outlines the fire resistance levels (FRL) required for the containment elements and the structure
- Section 4.6 summarises the FRL required for the containment elements and the structure.

The objectives for the fire resistance of containment elements and the structure are to prevent fire spread and the collapse of the structure until the occupants have safely evacuated. Protection must also be provided to fire fighting personnel during fire fighting operations. Protecting the structure and preventing collapse and fire spread also provides a level of property protection. The main objective, however, is life safety.

In the event of a C1 or C2 fire, the fire is controlled by means of self-extinguishment or occupant and/or fire brigade intervention and sprinklers respectively. There are no requirements for fire resistant barriers to contain the fire or fire resistance to structural elements to prevent collapse for these two fire sizes.

In an uncontrolled, C3, fire, the spread of the fire can be rapid, especially after flashover. Containment of the fire is required to delay the growth and spread of the fire until the occupants have evacuated. Providing fire resistance to the structural elements prevents collapse of the structure until the occupants have safely evacuated.

4.1 The Project 6 Report Proposed Requirements for the Fire Resistance of Containment Elements and Structure

The requirements for structural fire resistance levels from the Project 6 Report are:

- The materials of construction should generally comply with the general requirements of BCA clause C1.10 [3]. The BCA requirements for lining materials outlined Section 3.1 apply generally to the construction materials.
- 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.
- For a department store with a rise in storey of up to four, the following conclusions were reached:

  '-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[3].
-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.' (16.2)

- Ceiling space barriers should at least be provided approximately every 10th specialty shop or 50m whichever gives the closer spacing and at the junction of sprinkler zones. (14.4.1, 13.4.2) 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). No fire stop is required in gaps around penetrations, however gaps should not exceed 50mm at any location. (13.4.3)
- The current door construction is appropriate for doors at the entrance to fire-isolated stairways. (13.5)
- Doors from the mall to fire-isolated passages could have a FRL of -/30/-. (13.5)

Fires in escalators are not considered in the report as it is assumed that modern escalator construction is principally with non-combustible materials. Fires in lifts are not considered severe as with 'modern construction, fires associated with lifts are almost always limited to the lift shaft'. (8.3.2.4)

The report states that lightweight members will not be significantly affected by exposure to a sprinklered fire, based on the findings from the sprinklered tests conducted as part of the project. (12.2.4, 16.2) The sprinklered tests were conducted with non-combustible construction materials (ie cement sheeting on steel mesh on primary and secondary steel beams.) [7]

4.2 Fire Incidents in Retail Premises

The report *Case Studies of Fires in Retail Buildings*[4] reviews and documents the fatalities in 97 fires in retail buildings. The report has been reviewed and the fires from this report that occurred in buildings that were constructed with combustible materials, had rapid fire spread, or where the fire-rated construction failed (ie. it collapsed or the fire spread) are listed in Appendix B. Fires which occurred in buildings with combustible surface finishes are also listed in Appendix B.

A summary of the lessons from the case studies with respect to combustible structural materials, rapid fire spread and the failure of fire-rated construction is:

- Fires occurred in three shopping centres where the large fuel load was such that the fire spread rapidly irrespective of the combustibility of the structural materials. There was no compartmentation in these shopping centres and deaths occurred in two of these fires.
- Sprinklers extinguished or controlled fires in three buildings of timber framed construction.
- L'Innovation in Belgium was of predominately non-combustible construction. No compartmentation and combustible ceilings lead to rapid fire spread and 400 people being killed.

- In a shopping mall in New York, 2 people died from smoke inhalation despite the fact that the fire brigade contained the fire in one shop and the mall was evacuated within minutes.
- Fire walls are generally effective in controlling the spread of fire although two instances are recorded where fire walls collapsed or had unstopped openings.
- Eight instances occurred where the sprinklers were overwhelmed or ineffective due to the fire starting in an area not covered by the sprinklers eg in a canopy or ceiling space, partial collapse disrupting the sprinklers or the sprinklers being inoperative at the time of the fire.
- Smoke and fire spread occurred through ceiling spaces, ventilation shafts, ceiling vents, unstopped openings in fire walls, non-fire resistant walls, across combustible roofs or roof linings, via air handling units and combustible cabling. Smoke killed occupants outside the fire area in some cases.
- Non-compartmented, unsprinklered ceiling spaces are a major cause of rapid smoke and fire spread irrespective of the construction type of the building. Combustibles in the ceiling space exacerbate this.
- There were several instances where combustible and non-combustible roofs collapsed. In one instance the entire roof collapsed despite the fact that the fire brigade confined the fire to the shop of origin.
- In several cases, the fire spread rapidly after flashover.
- In 10 cases there was extensive damage or complete destruction of the entire building due to the fire. These buildings were constructed of combustible materials, non-combustible materials or a combination of the two.
- In two fires it was stated that combustible materials contributed to rapid fire spread.

4.3 Requirements for the Containment Elements

In four fires in the case studies, the fire spread rapidly irrespective of the combustibility of the structural materials. There was no compartmentation in these shopping centres and deaths occurred in three of these fires. Due to the large fuel loads in the shops and in sections of the mall, an uncontrolled C3 fire has the potential to spread rapidly, especially after flashover.

Containment elements slow down the spread of the fire giving greater time for the occupants to evacuate to safety. In a modern shopping centre it is difficult to completely contain a fire in a shop due to the requirements for open circulation. Shops are typically open to the mall, and in some instances the openings do not have doors, but grilles instead.

Shopping centres may contain many enclosed offices or store-rooms, where fire could be contained if the doors are closed and the enclosing structure is fire rated.

The spread of fire from a specialty shop can be horizontal through the opening to the mall or through the ceiling space, or vertical fire spread through the floor above. These mechanisms of fire spread are discussed in Sections 4.3.1, 4.3.2 and 4.3.3 respectively. The control of the fire spread to the fire isolated stairs and the carparks is discussed in Section 4.3.4.

4.3.1 The Mall

The fire can spread from a specialty shop through the opening to the mall to shops opposite across the mall, to combustibles in the mall or to adjacent shops.

Fire spread to shops opposite is by radiation across the mall. Calculations in the Project 6 Report indicated 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 6 m, assuming no combustible items in the mall.

Fire spread to combustibles in the mall will be a function of the type and distribution of the combustibles and their layout with respect to the shops and other combustibles in the mall. The main function of the mall is to provide for circulation of the occupants and hence the fire load density will be low compared to the shops. Therefore, although the fire may spread to combustibles in the mall and from there to other shops, the spread of fire in this manner is unlikely to be very rapid.

Flame spread to adjoining shops could be by radiation from the flames at the front of the store such that the glazing in the adjoining shops breaks and the fire spreads to combustibles in the adjacent shop. The spread of fire to the adjoining store by flame radiation is similar to spread of the fire to combustibles in the mall.

4.3.2 Ceiling Spaces

The review of the case studies indicated that non-compartmented ceiling spaces are a major cause of rapid smoke and fire spread. If the walls between the shops do not extend above the ceiling, providing a continuous ceiling cavity, then once the fire has broken through the ceiling, it can move horizontally within the ceiling space to adjacent stores. This method of fire spread is shown in Figure 1.

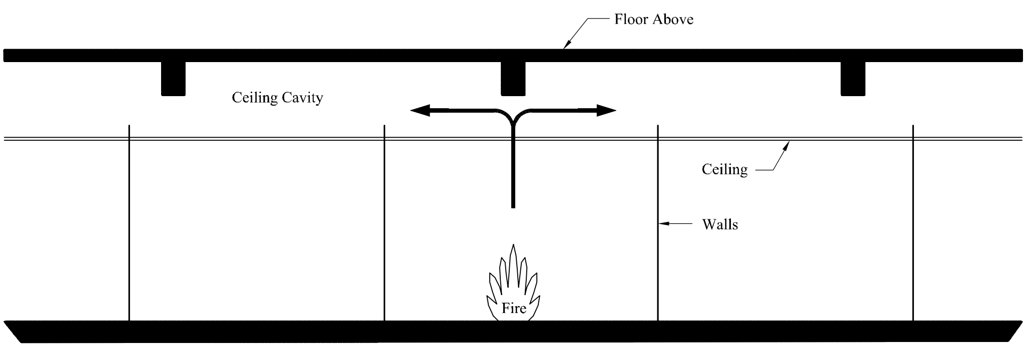

FIGURE 1: Fire spread through ceiling cavity

Fire spread to the adjacent stores, from the ceiling space, will occur by exposure of the combustibles to high levels of radiation when the ceiling has collapsed. If there is timber construction within the ceiling space, eg. the underside of the floor above is of timber, then the rate at which the fire will spread in this manner could increase. For fire spread through the ceiling space there are three combinations to be considered:

i. No combustibles exposed in the ceiling cavity,

ii. Timber exposed in the ceiling cavity,
iii. Local areas with no ceiling.

<u>No combustibles exposed in the ceiling cavity</u>
The floor structure above the ceiling space can be constructed from non-combustible materials, eg. concrete floor and steel beams, or be constructed from combustible materials, eg. timber, with a fire resisting system applied to the underside. The non-combustible ceilings are constructed from non-combustible materials, but they are not considered to have a fire resistance rating.

The time for the fire to penetrate into the ceiling space will depend on the construction of the ceiling. Results of tests on two types of ceiling tiles when subject to timber crib fires are that plaster tiles fell out in the period from 8 to 10 minutes into the test, while the mineral fibre tiles fell out between 11 and 14 minutes[12]. Tests carried out on commercial ceiling systems indicated that the time to penetrate the ceiling system ranged from a few minutes after flashover for ceiling systems incorporating mineral fibre tiles to 20 minutes for a basic plasterboard system[13]. Penetrations in the ceiling such as ventilation and light openings will increase the speed with which the fire will penetrate the ceiling. With no combustibles in the ceiling space, only flames and gases from the fire in the shop of origin can enter the ceiling space. Collapse of the ceiling in the adjacent shops could occur, with the Project 6 Report estimating that this would take up to 5 minutes from when the fire breaks initially into the ceiling space.

The presence of ceiling barriers at 50 m centres or every 10th specialty shop, whichever gives the closer spacing, as recommended by the Project 6 Report, would reduce the spread of the C3 fire and smoke. The ceiling barriers should be of protected lightweight construction, eg. plasterboard linings on steel or timber studs. There should be no gaps around the perimeter of non-combustible services penetrating the ceiling barriers. Any gaps around service penetrations through the ceiling barriers should be filled with a non-combustible material. This recommendation is more severe than the Project 6 Report which allowed a 50 mm gap around all penetrations. However, this recommendation is not requiring fire-rated construction, which would require additional expansive features such as fire dampers in ducts and intumescent collars around all plastic pipe penetrations. The ceiling barriers should be provided at the boundary between all shops (specialty shops and department stores) and the mall and between the specialty shops and the department stores. Figure 2 shows the ceiling barriers for this layout.

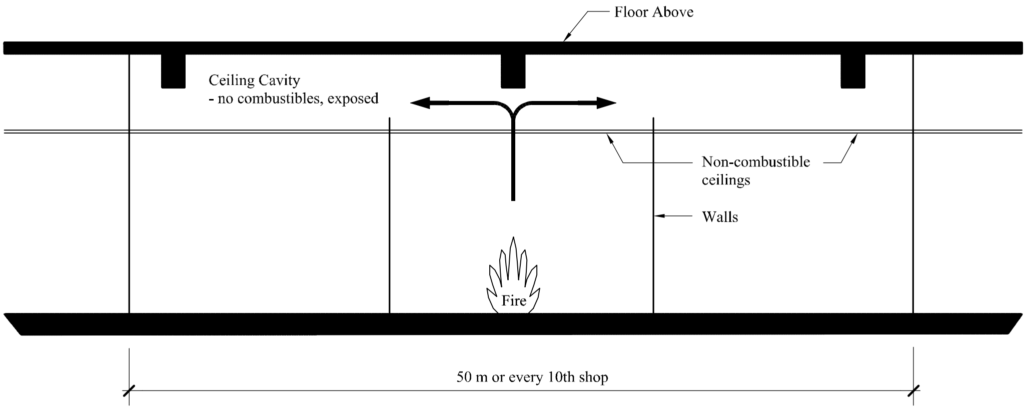

FIGURE 2: Ceiling barrier locations for no combustibles exposed in the ceiling cavity.

<u>Timber exposed in the ceiling cavity</u>

Timber exposed in the ceiling cavity can include timber on the underside of the floor above. The non-combustible ceiling will delay the spread of fire into the ceiling space. Once the fire has broken through the ceiling, the timber exposed in the ceiling cavity will commence to burn. This will lead to accelerated spread of fire along the cavity, and the radiation from the combustion of the floor structure will contribute to, and speed up, the spread of the fire to the adjacent shops once the ceiling in the adjacent structure has collapsed.

Where there is timber exposed in the ceiling cavity, fire rated ceiling barriers should be placed at closer spacings. Given the lack of a qualitative design method, it is recommended that they be placed at 25 m centres or at every 5th shop, whichever gives the closer spacing. This is to reduce the spread of the C3 fire and smoke. The fire rated ceiling barriers should be provided at the boundary between all shops (specialty shops and department stores) and the mall and between the specialty shops and the department stores. Figure 3 shows the fire rated ceiling barriers for this layout.

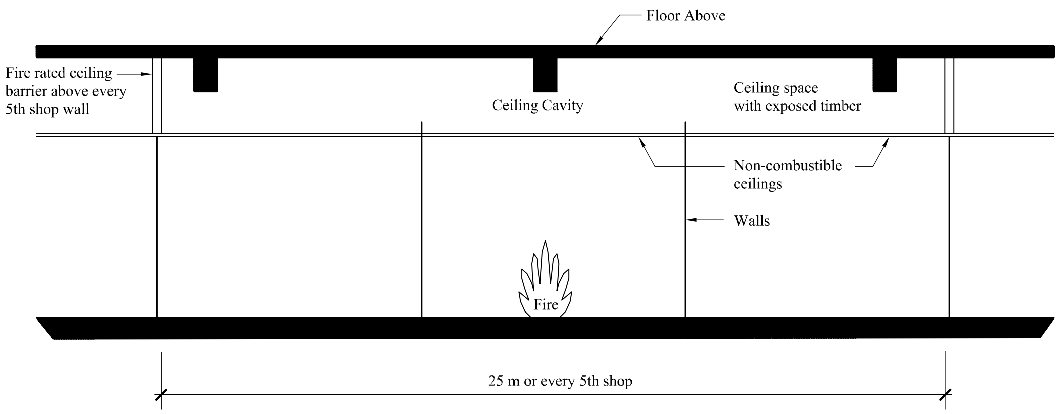

FIGURE 3: Fire rated ceiling barrier locations for timber exposed in the ceiling cavity.

Local areas with no ceiling

If there is no ceiling present, the underside of the floor above is exposed. Wood–based lining materials are not permitted on the ceiling, (Refer Section 3.5), therefore any timber exposed should be protected.

If no ceiling is present, there is no barrier to slow down the spread of fire to the ceiling space from the room of origin. The fire could spread rapidly into the ceiling space and into the adjacent shops once the ceiling in the adjacent structure has collapsed. Therefore, where there is no ceiling present, ceiling barriers should be provided to the periphery of the area. If there are no combustibles exposed in the ceiling cavity, the ceiling barriers should be of protected lightweight construction, eg. plasterboard linings on steel or timber studs. If there is timber exposed in the ceiling cavity, the ceiling barriers should be fire rated. Figure 4 shows the layout of the ceiling barriers for this configuration.

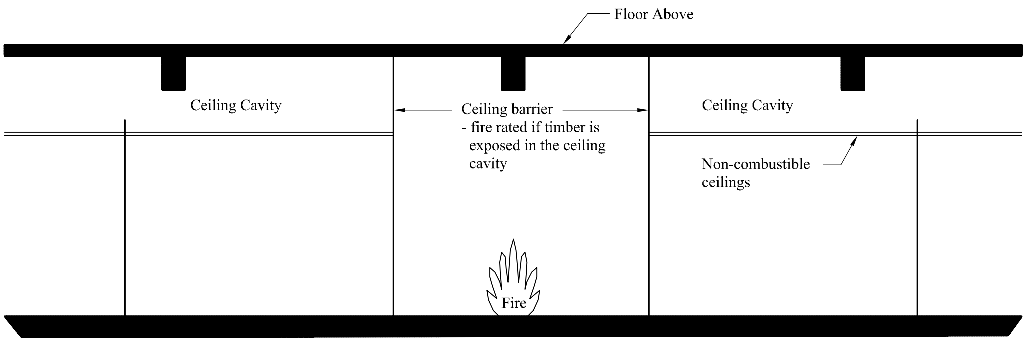

FIGURE 4: Ceiling barrier locations where no ceiling is present.

In summary, ceiling cavity barriers should be located as follows:

- Where there are no combustibles exposed in the ceiling cavity, ceiling cavity barriers should be provided at 50 m centres or every 10th shop, whichever is less, as recommended by the Project 6 Report. The ceiling barriers should be provided at the boundary between all shops (specialty shops and department stores) and the mall and between the specialty shops and the department stores. The ceiling barriers should be of protected lightweight construction, eg. plasterboard linings on steel or timber studs. Any gaps around service penetrations through the ceiling barriers should be filled with a non-combustible material.
- Where the ceiling cavity contains exposed timber, it is recommended that fire rated ceiling cavity barriers be provided at 25 m centres or at every 5th shop, whichever is less. Fire rated ceiling barriers should be provided at the boundary between all shops (specialty shops and department stores) and the mall and between the specialty shops and the department stores.
- If there are local areas with no ceiling, ceiling cavity barriers should be provided to the periphery of the area. If there is no timber exposed in the ceiling cavity, the ceiling barriers should be of protected lightweight construction, eg. plasterboard linings on steel or timber studs. If there is timber exposed in the ceiling cavity, the ceiling barriers should be fire rated.

of the fire. Structural design for fire conditions is essentially the same as design for normal temperatures, with certain important differences including:

- the applied loads are less
- internal forces may be induced by thermal expansion
- strengths of materials may be reduced by elevated temperatures
- cross section areas may be reduced by charring or spalling
- smaller safety factors can be used, because of the low likelihood of the event
- deflections are not important (unless they affect strength)
- different failure mechanisms need to be considered (eg membrane action)

Many structural members of various materials (eg timber, concrete or steel) have significant levels of fire resistance with no applied fire protection. Assessment of structural fire resistance must include consideration of structural factors such as axial restraint, moment redistribution and tensile membrane action. The fire resistance can be enhanced by applying a passive fire protection system to the structure, eg. concrete filling of hollow sections, intumescent paint or other protective coatings to structural steel or proprietary board systems applied to light timber framing.

The required FRL is should be independent of the construction materials. In high fire load occupancies such as shopping centres, combustible construction materials such as heavy timber beams and columns will not contribute significantly to the fire load. Light timber frame walls and floors will be protected by proprietary board systems to achieve the required fire resistance ratings, so that the timber framing cannot contribute to the fire load until well after the occupants have evacuated the building.

4.5 Fire Resistance Level, FRL

The FRL of the structure and fire separations or containment elements should be sufficient to prevent fire spread and collapse of the structure until the occupants have safely evacuated, independent of the building materials. The performance-based design recommendation is that the fire resistance levels for the structure and for the containment elements should exceed the time required for all occupants to escape from the building.

A minimum FRL of 30 minutes should be specified. Fire resistance levels below 30 minutes are not meaningful, as the standard fire resistance test was not designed to test for short periods. The lack of a preflashover period in the standard fire test is insignificant for long fires, but very important for short fires. The products which will be used to achieve fire ratings of less than 30 minutes (e.g. 9.5mm standard gypsum board) are not formulated for fire conditions and can have severe local damage after a few minutes exposure to a localised preflashover fire. For example, 10 or 15 minutes of severe local burning might result in an integrity failure of a 15 minute barrier before flashover even occurs. Most of these products have never been tested in such conditions. The minimum requirements for acoustics and impact resistance of most barriers will achieve a FRL of 30 minutes or above, therefore the 30 minute FRL is easily achievable at minimal cost.

Note that all reinforced concrete structures and many steel structures can be designed for 30 minute FRL with little or no applied fire protection, especially if the ductile large deformations mentioned in the Project 6 Report are considered.

This design proposal is somewhat simplistic, but it provides a rational basis for determination of the required fire resistance levels. There are many assumptions and simplifications built into this proposal, but it provides a simple basis for design. This proposal may be seen as more conservative than the Project 6 suggestion that fire resistance is only necessary to get people off the floor above the fire, but it is believed to be a minimum requirement if life safety is to be considered seriously, given a fully developed fire following sprinkler failure.

The total evacuation time is measured from the time of ignition. The evacuation time is given by:

$$t_{ev} = t_d + t_a + t_o + t_I + t_t + t_q + t_s$$

where:

t_{ev}	is the calculated evacuation time measured from ignition,
t_d	is the time from ignition until detection of the fire (by a building occupant or by an automatic detection system),
t_a	is the time from detection until an alarm sounds,
t_o	is the time from alarm until the time occupants make a decision to respond,
t_i	is the time for occupants to investigate the fire, collect belongings, fight the fire,
t_t	is the travel time, being the actual time required to traverse the escape route until a place of safety is reached, including way-finding,
t_q	is the queuing time,
t_s	is the safety factor. [14]

An alternative detection and alarm system to the sprinkler system should be provided to give notification to the occupants in the event of a C3 fire. Dense smoke is not an adequate cue to evacuate the building, as there will be areas such as offices, cinemas and remote areas in multi-level department stores in which occupants will not see dense smoke before the spread of the fire will prevent their safe evacuation. The calculation of the evacuation time should incorporate the alarm system used.

The term t_d may be determined from computer fire growth models. The term t_a should be estimated from knowledge of the alarm system or from knowledge of human behaviour.[14]

The factors affecting the time to move, $t_o + t_i$, include the occupants alertness, mobility, role, position, commitment, focal point and familiarity with the building, and the type of alarm. Methodologies for calculating the time to move are proposed by Jonathan Sime [15] and Hamish MacLennan[16]. A mathematical manipulation of MacLennan's data is proposed by R. Marchant. For a shopping centre, with a typical AS2220 alarm system, the time to move is calculated by Sime's, Maclennan's and Marchant's methods as 4.44, 9.15 and 5.22 minutes respectively[17].

The travel time, t_t, and queuing time, t_q, can be calculated using a simplified method of hand calculation based on the SFPE handbook[8] or by the use of an evacuation model such as SIMULEX[18]. If the fire resistance levels of the walls between the shops and the carparks and fire-isolated stairs exceeds the expected duration of a C3 fire, then they are safe places such that the evacuation time is the time to get to those places. If the fire resistance levels do not exceed the expected duration of the fire, then the carparks and fire-isolated stairs are not safe places and the evacuation time must include evacuation from those places.

Sprinkler failure or isolation is a rare event, therefore the factor of safety applied to the evacuation time for the calculation of the fire resistance rating can be minimal. With a soundly managed sprinkler system, the effectiveness of the sprinklers was given as 98.5% for specialty shops and 99.5% for major stores in the Project 6 Report. A C3 design fire, which does not go out, should be used in the calculation of the fire resistance provided by the structural and containment elements. In many cases the C3 fire should be considered to spread beyond the room of origin, depending on the layout of the building.

5 FIRE RESISTANCE OF TIMBER MATERIALS

This section describes the wide variety of timber structures that could be used in construction of shopping centres, and discusses methods of providing fire resistance to these and other timber members and timber assemblies.

5.1 Types of timber structures

When assessing fire resistance, timber members and timber assemblies are generally separated into two categories; heavy timber structures and light timber frame construction. "Heavy timber" includes large sizes of solid sawn timber and glue laminated timber (glulam) where the minimum dimension is no more than about 100mm, and fire resistance is achieved through the predictable rate of charring on the exposed timber surfaces. "Light timber framing" describes a large number of structural systems incorporating timber in stud and joist sizes, where the minimum dimension is no more than 50mm, and fire resistance is achieved by protecting the wood with gypsum board or similar non-combustible lining materials.

5.1.1 Timber floors

The most common timber floor systems have plywood or particle board flooring supported on light timber joists, spanning between load-bearing walls or beams. The joists can be selected from a wide range of products, with spans from two to ten metres depending on the design. The types of available joist assemblies include solid sawn timber joists, LVL planks, and parallel chord timber trusses with timber or steel web members. There are many possible designs of timber I-beams with plywood, hardboard or corrugated steel webs. Some light timber floor systems are constructed as stressed-skin panels utilising the top and bottom lining materials as structural flanges.

Heavy timber floor systems consist of solid timber decking, which can be made of large glulam planks, LVL planks, or decking made with joist-size timber nailed together board by board. Timber decks can be continuous over several supports.

A composite timber-concrete floor system consists of nailed timber decking acting compositely with reinforced concrete topping, incorporating shear connectors between the timber and the concrete. Such systems are increasingly used in Europe.

Some precast prestressed concrete plank floor systems use permanent timber formwork as the exposed lower surface between the concrete planks.

5.1.2 Timber walls

Most timber walls are light timber frame walls with vertical timber studs between top and bottom timber plates. These walls are always lined with sheet materials, and possibly include solid blocking or diagonal bracing between the studs. Load-bearing walls and non load-bearing partitions have similar construction, although the stud sizes will be larger or the stud spacing smaller in heavily loaded walls.

5.1.3 Timber beams

Timber beams which support floor systems are most likely to be glulam beams, either as simply supported "post-and-beam" construction, or moment-resisting frames. Simply supported glulam beams may be short single span beams, or long beams continuous over several intermediate supports. Supports can be columns or walls. Moment-resisting glulam frames have strong connections between the beams and the columns, using exposed nail-plates, bolts and steel plates, or epoxied steel rods which are hidden from view.

5.1.4 Timber roof systems

There is an extremely wide range of possible timber roof systems. Large span timber roofs are likely to incorporate glulam structural members as beams, arches, trusses, or frames. These can be designed as two-dimensional systems or three-dimensional space-frames. Other options include domes and folded plate structures. Many timber truss systems will include steel members. Roof systems are not considered further because the roofs are not required to be fire rated.

Timber materials include heavy timber structures, such as solid timber floors, beams and columns, and light timber frame construction, such as floors, load-bearing walls and non load-bearing walls. This chapter outlines the fire behaviour and the calculation of the fire resistance level for each of these structural members.

5.2 Heavy Timber Structures

Heavy timber construction[19,20] includes beams, columns, solid wood floors, truss members made from sawn timber or glue laminated timber. Heavy timber refers to timber members whose smallest dimension is about 100mm. Heavy timber construction has been recognised as having very good fire resistance.

When large timber members are exposed to fire, the surface of the wood ignites and burns. As the burning continues, the burned wood becomes a layer of char that insulates the solid wood below and reduces the rate of burning. The layer of char shrinks, making it thinner than the original wood, causing fissures which facilitate the passage of combustible gases to the surface[21]. The char layer does not usually burn away because there is insufficient oxygen in the flames at the surface of the char layer for oxidation of the char to occur. The wood below the char layer becomes hot, so that the moisture in the wood evaporates. Some of this moisture travels out to the burning face, but some travels into the wood, resulting in an increase in moisture content in the heated wood a few centimetres below the char front.

As the temperature increases, the modulus of elasticity, and the tension and compression strength both perpendicular and parallel to the grain reduce. The reduction increases with increasing moisture content[22,23,24,25].

The strength of a structural timber member is reduced in fire, because the wood converted to char has no strength and the increase in temperature and moisture gradients below the char layer reduce the strength and increase the plasticity of the remaining section. The increase in plasticity is important because if the heated wood were to lose strength with no increase in plasticity, cracks would occur in the heated tension zone of the beam, leading to premature failure in fire. The plastic behaviour of the heated wood allows redistribution of stresses into the cooler wood further from the char layer.

The char layer has no strength, therefore for a timber member exposed to fire, the original cross section is reduced by the depth of char. The boundary between the char layer and the remaining wood section is quite distinct, and corresponds to a temperature of approximately 300^{o}C. The remaining wood section is heated in a layer about 40 mm thick, below the char front. The wood at temperatures above about 200^{o}C is known as the pyrolysis zone. The inner core of the member is at its initial temperature. The residual cross section is capable of supporting considerable loads, providing a level of fire resistance that depends on the ratio of the load at the time of the fire to the initial design load. Failure occurs when the residual cross section is stressed beyond its ultimate strength.

The design of the timber members can be by either using the residual cross section dimensions with reduced material properties, or by using an even smaller residual cross section assuming that it is unaffected by temperature.

The charring rate of timber in the standard fire test is quite predictable, depending on the density and moisture content of the wood. Many national codes specify a constant charring rate throughout exposure to the standard test fire, the value depending on the wood density.

All tests of timber exposed to fire show some rounding of the corners of rectangular members, due to the fact that the corners are subjected to heat transfer from two surfaces. Most design codes use the simple relationship whereby the radius of the rounding is equal to the depth of the charred layer.

5.2.1 Beams

Large timber beams exposed to fire have demonstrated excellent predictable behaviour. Beams are designed using the methods described above. It is important to determine which surfaces of the beam are exposed to fire. Most beams provide support to fire resisting floor systems, so the top edge of the beam is not exposed to the fire.

Beams must be provided with resistance to lateral torsional buckling. Lateral support to the compression edge of the beam will prevent lateral buckling. Lateral restraint of the tension edge can help to resist buckling, but only if the residual beam has sufficient torsional rigidity.

Shear stresses are not normally a critical design consideration in rectangular beams, but may become important for I-beams or beams with holes cut out for services to pass through. Design can be made using the fire-reduced cross section with allowance for reduced strength of the residual cross section.

Beam deflections can be calculated using the reduced loads, reduced section modulus and a reduced modulus of elasticity. Deflections are not usually of concern because the strength limit state is more important than serviceability limit state during fire exposure.

5.2.2 Columns

The strength of a short column depends on the crushing strength of the material. Under fire exposure this can be calculated from the reduction of cross section and the reduced strength of the wood in the residual cross section. Long columns are susceptible to buckling failures, so the failure load depends on the moment of inertia and modulus of elasticity of the residual cross section. Lateral stability is important for columns. The likelihood of buckling will increase as the fire progresses because the reduced cross section dimensions increase the slenderness of the column. Elements providing lateral restraint to the columns must have sufficient fire resistance to provide restraint to the column for the duration of the fire.

5.2.3 Floors

Solid wood decking includes solid timber or glulam timber planks laid flat or butted together with tongue and groove edges, and timber planks set on edge and nailed together. Assessment of fire resistance of solid wood decking must consider all three possible failure criteria of insulation, integrity and stability.

The strength, or stability, criterion can be assessed in the same way as for beams and columns. If the planks are fitted tightly together the fire exposure will cause charring only on the lower surface. This results in gradually decreasing thickness as the fire proceeds.

In order to meet the integrity criterion, it is essential that no flames or hot gases pass through the floor, because these could lead to ignition of items on the upper surface. Difficulties arise at the junctions between the planks, and are complicated by possible shrinkage of wood that often occurs during the life of a building. Tongue and groove joints are the best solution, where it can be assumed that if the gaps are large enough then the tongue will char at the same rate as the other exposed surfaces. If the gap is less than 5 mm wide then the temperature within the gap will remain low enough that charring will not occur.[26] A maximum of 3 mm is recommended in German literature.[27] Intumescent paint can be used in the junctions to improve the integrity during fire.

If the integrity and stability criteria are satisfied, there will be no problem meeting the insulation criterion, because the thickness of remaining wood required to carry applied loads will be much greater than that required to prevent excessive temperature rise on the top surface.

5.3 Light Timber Structures

In light timber frame construction[19], walls and partitions are usually constructed with sawn timber studs. Floors consist of plywood or particle board sheeting nailed or screwed to joists which may be sawn timber or engineered products such as LVL joists, wood I-joists or parallel chord trusses. Light steel framing can also be used for this type of construction. Because of the small size of timber and steel members used in this type of construction, fire resistance must be based on protective materials, by far the most common being gypsum board. The gypsum board is used as wall and ceiling linings, where it provides a wearing surface as well as contributing to acoustic, thermal and fire separation between rooms.

In most wall construction, the gypsum board is fixed directly to the studs using nails or screws. An elastomeric construction adhesive may also be used in some situations, but should be ignored under fire conditions. Ceiling linings may be connected directly to the joists, but are often suspended on a wood or steel framing system. Light steel frame construction is similar to light timber construction in that the lining is an essential part of the fire resistive construction and the quality of the gypsum board and its fixings are important.

In order to provide satisfactory fire resistance, the assemblies must meet the three criteria of integrity, insulation and stability. Non load-bearing partitions and load-bearing walls and floors, all of which are containment elements, must meet both the integrity and insulation criteria. Load-bearing walls and all floors must also meet the stability criterion. Fire resistance ratings are assigned to completed assemblies of light frame construction, and not to individual components.

The integrity criterion applies to the whole assembly, which must not allow the passage of flames or hot gases during the fire resistance period. It is essential that any protective material, such as gypsum board, remain in good condition long enough for the assembly to perform its function. Assessment of integrity can only be done by large scale testing. Large scale testing allows factors such as shrinkage of gypsum board, cracking during structural deformations and the resistance of the gypsum board to falling off during a fire.

The insulation criterion for fire resistance requires that the temperature on the unexposed face remain below a certain critical temperature, below which there is no danger of ignition on the unexposed surface and subsequent fire growth. The insulating properties of an assembly depend on the geometrical arrangement and the component materials. The type and thickness of the board, the cavity, the presence of insulating material and moisture effect the insulating performance of the assembly. Using the ISO 834 criteria, the assembly is considered to have failed the test when the average temperature rise on the unexposed surface exceeds 140^{o}C, or the maximum temperature rise at any point exceeds 180 ^{o}C.

The stability criterion applies to all load-bearing elements. Most of the strength of light frame assemblies is in the timber or steel members. Lining materials provide useful lateral stability to the timber members.

The design of light frame assemblies is usually by reference to results of standard fire resistance tests or reference to listed approvals based on such tests, rather than by direct calculation. Most approvals are based on listings of approved fire resistance ratings produced by approval organisations, trade organisations, manufacturers or testing and approval agencies. These listings are derived either directly from tests or from expert opinions based on successful tests. Each rating has specific requirements for assembly and fixings.

Most manufacturers of gypsum board worldwide have proprietary fire resistance ratings for timber and steel framed assemblies containing their products. These fire resistance ratings usually include a specification of framing members, lining material and fixing methods, all of which must be followed if the assembly is to meet the intended rating.

Extrapolation from a listed rating can be made to achieve a fire resistance rating for a wall with a different height or different load from that tested. There are several calculation methods available for assessing the fire resistance of light timber frame construction, but these are not often used because they tend to be much more complicated than selection of proprietary systems. The integrity criterion can not be checked by calculation.

5.3.1 Load-bearing Walls

The load capacity of the timber studs depends on the size, temperature and moisture content of the residual cross section. Charring of the wood begins when the temperature reaches about 300^{o}C. The rate of charring is less than that occurring for wood members exposed directly to a furnace environment.

If the cavity is filled with batts, the gypsum board on the fire exposed side heats up much faster than for an empty cavity, leading to earlier dehydration and possible falling off of the board. Well fitting rock wool insulation will remain in place and protect the studs and unexposed lining from the fire. Charring of the studs occurs only on the edge in contact with the fire, so the loss of strength is much less than for an empty cavity. If the cavity is filled with glass fibre batts, and the fire-exposed gypsum board falls off, the glass fibre batts will rapidly melt leaving the studs and the remaining lining directly exposed to the fire.

Failure of load bearing walls, during a fire test, is usually by buckling of the studs about the strong axis, away from the furnace. Buckling about the weak axis is prevented mainly by the lining materials on the unexposed face, as the gypsum board on the exposed face has lost strength through dehydration.

5.3.2 Non-Load-bearing Walls

In a non load-bearing wall, the wall is not required to meet the stability criterion. The studs must retain only enough strength to hold the lining in place for the duration of the fire, so the studs may be almost completely burned away by the end of the fire.

5.3.3 Floors

Timber joist floors behave similarly to the load-bearing walls described above. Because they are flexural members, the joists are not subject to buckling about their strong axis. Buckling about the weak axis is prevented by the floor diaphragm on the cooler side of the assembly and fixed to the compression edge of the joist, for a simply supported floor assembly exposed to fire from below.

Timber joist floors are usually protected from fire by one or two layers of gypsum board or similar fire-resistive material. The gypsum board can be fixed directly to the underside of the joists, to battens or resilient rails which are fixed to the joists, or to a suspended ceiling grid. Some fire-rated suspended ceiling tile systems also have approved fire resistance ratings, but these require special protection to recessed lights and other penetrations.

For assemblies relying on a ceiling membrane to provide fire resistance, it is recommended that the fire resisting membrane be attached to the underside of the floor structure and an additional suspended ceiling be provided in the shops. This allows recessed light fittings and building services to be placed in or on the suspended ceiling without penetrating the fire resisting membrane, and reduces the amount of combustible surfaces within the ceiling cavity.

6 CONCLUSIONS

These conclusions are based on the expected behaviour of the building and the occupants in the unlikely event that a fire occurs when the sprinkler system is not operative.

If sprinklers could be considered 100% effective, there would be no reason to limit the type of building materials, and no reason to have fire resistance levels for any part of the structure, but sprinklers do not always operate as expected. The Project 6 Report states:

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

If a fire occurs when the sprinklers are not operative, an uncontrolled fire could occur, and the design objective is to ensure life safety, but no property protection.

The main recommendations are:

- The Project 6 Report should be developed into a design guide that includes wood-based building materials on an equal footing with steel and concrete.
- Major improvements suggested for the Project 6 Report include the following:
    - A fire detection and alarm system should be provided in the mall, large shop and unoccupied areas, in addition to the automatic sprinkler system. Occupants, initially remote from the fire, require a cue other than dense smoke to initiate evacuation.
    - The relationship between the Project 6 Report and other documents such as the Building Code of Australia should be clarified.
    - The safety of shopping centres with roof or basement carparks should be addressed explicitly.

The overall conclusions are that:

- Timber should be permitted as a structural material on an equal footing with steel and concrete, provided that the fire resistance levels are adequately defined.
- Wood-based lining materials should be permitted in certain limited areas of shopping centres.

Lining materials:

- Wood-based panel materials should not be permitted as linings on ceilings, in order to reduce the possibility of rapid spread of fire.
- Wood-based lining materials should not be permitted on the walls in exitways or fire-isolated stairs.
- Smaller areas of wood, such as exposed timber beams and columns, are acceptable throughout.

Structural and containment elements:

- The required fire resistance levels for all structural members and containment elements should be independent of the construction materials. Wood based materials, including heavy timber construction and light timber frame construction should be permitted throughout.

- Whatever the building materials, the fire resistance levels for the structure and for the containment elements should exceed the time required for all occupants to escape from the building. The calculated evacuation time must include the time for detection, the sounding of the alarm, occupant decision making, investigation and first-aid fire fighting, queuing time, travel time and a safety factor. This should include the time required to evacuate the carparks unless they are separated by additional fire-rated construction.

- The minimum level of fire resistance provided by the structure and the containment elements should be 30 minutes, regardless of the building materials. No fire resistance is necessary for the roof or elements supporting the roof.

- The containment elements required to slow down the spread of fire, to give the occupants sufficient time to evacuate to safety, as required by the Project 6 Report, are:
  - Floors, but not the roof,
  - Walls to fire-isolated stairs,
  - Walls separating the carpark from the rest of the shopping centre,
  - Ceiling barriers at 50 m centres or every 10th shop, whichever is less, where there are no combustibles in the ceiling cavity.

- The additional requirements for the containment elements are recommended as follows:
  - Ceiling cavity barriers should be provided at the boundary between all shops (specialty shops and department stores) and the mall and between the specialty shops and the department stores.
  - Ceiling cavity barriers should be provided to the periphery of local areas which contain no ceiling.
  - The ceiling barriers should be of protected lightweight construction, eg. plasterboard linings on steel or timber studs. Any gaps around service penetrations through the ceiling barriers should be filled with a non-combustible material.
  - Where the ceiling cavity contains exposed timber, fire rated ceiling cavity barriers should be provided at 25 m centres or at every 5th shop, whichever is less and all ceiling cavity barriers should be fire rated.

- For timber floor assemblies relying on a ceiling membrane to provide fire resistance, it is suggested that the fire resisting membrane be attached directly to the underside of the floor structure and an additional suspended ceiling be provided in the shops. This allows recessed light fittings and building services to be placed in or on the suspended ceiling without penetrating the fire resisting membrane, and eliminates timber surfaces in the ceiling cavity.

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APPENDIX A
SUMMARY OF THE PROJECT 6 REPORT

This section contains a chapter by chapter review of the Project 6 Report, *Fire Safety in Shopping Centres*[1]. The review is presented in tabular form with the summary of the Project 6 Report and comments in separate columns. The comments relate to the objectives of the Project 6 Report, also covering inconsistencies and the impacts of combustible finishes and combustible structure.

1. Introduction (pages 1-6)

Project 6 Report	Comments
The type of building to which the report applies is defined as 'a low-rise sprinklered shopping centre having a rise in storey of up to four.' (1.1) It covers buildings that contain 'a covered walkway or mall and the following classes of buildings, with respect to the Building Code of Australia (BCA): *Class 6 –* Retail including specialty shops, major stores, department stores, supermarkets *Class 9b –* Cinemas *Class 7 –* Carparks including open deck and sprinklered carparks *Class 5 -* Offices.' (1.1)	No statement is given in the introduction as to the type of construction materials to which these guidelines apply.
The purpose of the report is defined as, after a review of the BCA requirements, '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.' (1.1) Life safety and property protection are recognized as needing to be considered. (1.1)	Property protection and life safety need to be considered.
The issues that must be addressed are highlighted as design, construction, installation, commissioning, and the management of the installed systems. The method of approach for the project is defined and an overview of the report given. (1.3)	Limitations on size, shape or layout, if any, are not given.

2. BCA Requirements and Key Issues (pages 7-17)

Project 6 Report	Comments
Chapter 2 summarises the current requirements and identifies specific regulations and areas for consideration due to cost or safety concerns. Shopping centres have particular attributes which contribute to fire safety, such as: the occupants are generally alert and mobile, a high level of management control, maintenance activities and security surveillance which help identify and reduce fire starts.	The performance requirements for shopping centres designed to these guidelines are not directly identified.

<table>
<tr><th>Project 6 Report</th><th>Comments</th></tr>
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A previous report, BCA Fire Safety Requirements for Shopping Centres[28], analyses in detail the requirements for shopping centres based on the 1990 edition of the BCA. The 1996 version of the BCA recasts the code into performance terms, and also has deemed-to-satisfy provisions. The Project 6 Report states that although some provisions have changed between the 1990 and 1996 versions of the code, little changed that directly affected the document and it included any changes that were appropriate.

The issues that are to be addressed in the report are identified with a number of questions:

Separation requirements between different classes of building within one building structure? (2.1)
Appropriate door construction, if separation is required? (2.1)
Fire-resistance levels (FRL) for columns, beams, floors and walls? (2.1)
Applicable exit spacing and width requirements? (2.2)
What areas should be isolated with walls to facilitate safe egress, and appropriate door construction at openings? (2.2)
Should an Emergency Warning and Intercommunication System, EWIS, be required, and if so, its characteristics? (2.2)
Access for fire fighting and other emergency vehicles? (2.3)
Are hydrants required, and if so, what are the best locations? (2.4)
Under what circumstances are fire control centres necessary? (2.4)
The reliabilities and appropriate design parameters of smoke control systems? (2.5)
Characteristics required of smoke exhaust/venting systems for fire safety? (2.5)
Reliability of sprinklers and how this can be maintained/improved? (2.7)
Grade of water supply in a building having a height of less than 25 m? (2.7)
Circumstances under which it is necessary to sprinkler the roof of a mall? (2.7)
How boundary wall construction around an atrium contributes to fire safety? (2.6)
Purpose and effectiveness of sprinklering an atrium roof? (2.6)
Circumstances under which MCP alarms and a standby power supply are required with an atrium? (2.6)

The report address these key issues, and a summary of the responses are given in Section 16, Conclusions and Recommendations.
</td><td>
Some of these questions are answered later in the report, but some are not addressed adequately, ie.

EWIS characteristics required.
Smoke exhaust/ venting system characteristics for property protection and fire fighting.
Grade of water supply.
Circumstances under which standby powers supply are required in an atrium.

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3. Fire Incidents in Retail Premises (pages 18-20)

Project 6 Report	Comments
A report *Case Studies of Fires in Retail Buildings*[4] was prepared which reviewed and documented the fatalities in 97 fires in retail buildings. The fires reviewed occurred over the last 30 years, and the source of the data is such that caution should be used in drawing general conclusions. The case study findings are summarised as follows: • The majority of fires appear to have been started by electrical faults or arson. Welding work during renovation caused some fires. • Fires only developed to a significant size, in the majority of situations, if the fire was initiated in a remote area. • In a few situations, combustible ceiling tiles led to rapid fire spread. • A major mechanism of fire spread to other parts of the building appears to have been via a combustible ceiling or through the ceiling space. There were many situations where the ceiling space was not sprinklered. • Sprinklering of only sections of a shopping centre is generally not a sound practice as substantial damage (including water damage) may occur to the sprinklered sections if the fire is initiated in a non-sprinklered part. • Some cases occurred where the presence of combustibles or combustible construction within parts of a building (eg. ceilings, verandahs and awnings) allowed a significant fire to develop such that the sprinklers were overwhelmed and not adequately able to control the fire. No sprinkler system information was given for these cases. • Two fires occurred when the sprinklers had been isolated overnight, which caused almost complete destruction of the building. • The fire brigade was most effective in controlling and extinguishing small fires. Fires can be kept small by the action of occupants or sprinklers. (3.2) Data from Australia and USA on deaths in fires in retail premises gives the death rate at about 1 per 1000 fires. The majority of victims were impaired, asleep or involved with flammable liquids. (3.3)	Note that caution is required in drawing general conclusions due to the data source. Combustible ceiling tiles led to rapid fire spread. Combustible ceiling or ceiling spaces are a major mechanism of fire spread. Some cases where the sprinklers were overwhelmed due to the presence of combustibles or combustible construction. Almost complete destruction of the building in two cases where the sprinklers had been isolated overnight.

4. Fire Statistics (pages 21-24)

Project 6 Report	Comments
A report *Analysis of US Retail Fires*[5] was prepared which gives a detailed statistical study of retail fires in the USA. The key findings are summarised as follows: • The average fatality rate in the USA for civilians in retail premises is 1.12 deaths per 1000 fires, and for shopping complexes is 0.74 deaths per 1000 fires. This death rate does not include the beneficial effects of sprinklers. (16.2) No information is given on the construction or layout of the buildings in which these fires occurred or whether or not the buildings meet the current fire code requirements. The fatality rate increases with increasing fire size. (4.2) • Where flame damage was recorded, 47% of fires were confined to the object of fire origin, 80% of fires were confined to the room of fire origin. The effect of sprinklers on the extent of flame damage was not recorded. (4.3) • More fires occur in the daytime than at night. Daytime fires are more likely to be confined to the object and room of fire origin, and record a greater rate of injury. Fires at night have a greater chance of becoming large, and the death rate is higher. (4.4) • Sprinkler effectiveness is indicated as high. With sprinklers, 60% of fires were confined to the object of origin, and 94% to the room of origin. Without sprinklers 44% of fires were confined to the object of origin, and 75% to the room of origin. (4.5)	

5. Survey of Shopping Centres (pages 25-26)

Project 6 Report	Comments
A report *Shopping Centre Review*[6] was prepared which looked at construction details, quantity and distribution of combustibles, exit details and construction, sprinkler systems, smoke control systems, fire warden systems and evacuation drills, fire brigade facilities, detection and alarms in shopping centres in Australia. The report also looked at management and maintenance policies, fire incidents and procedures, refurbishment practices and frequencies. Information was gained from a 'very comprehensive study of a major shopping centre in Victoria over a continuous two month period and through visits to 11 shopping centres in Victoria and New South Wales.' The shopping centre in the comprehensive study had a gross retail area of 58000 m^2, with a four-storey department store at the end of a two-storey mall. The details of the study were not given in the Project 6 Report.	

6. Fire Tests (pages 27-35)

Project 6 Report	Comments
11 full-scale fire tests were conducted to investigate the effects of fires in specialty shops and major stores in a shopping centre. *Simulated Shopping Centre Fire Tests*[7] reports in detail on the fire tests, with a summary of the fire tests given in this chapter. Fire tests were conducted to simulate a fire in a toy store and in the storage area of a shoe shop, both sprinklered and unsprinklered (non-cellulosic material stored in a shelved arrangement), and sprinklered fires in a clothing store (common in modern shopping centres) and bookshop/newsagent (cellulosic combustibles). The fire tests were reported as follows: • 1. Sprinklered Toy Display Within a Large Store Shelving, predominantly plastic combustibles and sprinkler head location prevented sufficient water from getting to the seat of the fire and it continued to spread along the shelving, but not to other racks. It was the most severe sprinklered fire in terms of smoke production, with the sprinklers increasing the volume but decreasing the concentration. • 2. Unsprinklered Toy Display Within a Large Store This was the most severe unsprinklered fire in terms of quantity and rate of smoke production and air temperatures. The peak heat release rate was estimated as 25 MW. • 3. Sprinklered Shoe Storage The fire was slow to develop due to the compact nature of the combustibles. The air temperature at sprinkler activation was high. Sprinkler spray patterns meant that little water reached the seat of the fire, and in a real fire situation, it appeared that multiple sprinkler head activation would have been likely which would result in the sprinkler system being overwhelmed. This indicated that the sprinkler setout should suit the raking arrangement. • 4. Unsprinklered Shoe Storage This fire was slow to develop. The fire reached a peak heat release rate of 40 MW, and is one of the most severe unsprinklered fires likely to be encountered in a retail situation. • 5-9. Sprinklered Clothing Shop The sprinklers on the ceiling were fast to activate, and rapidly controlled and reduced the intensity of the fire. The fire was not extinguished due to the shielding effect of the clothing. • 10-11. Sprinklered Book Shop It took considerable time for the fires to build to sufficient intensity for the sprinklers to be activated. The sprinklers extinguished the fires. The smoke was whiter than in tests 5-9 and contained substantial steam.	The unsprinklered tests, 2 and 4, are for a shop of a specific size. ie the fire can not spread beyond the fire test area. Can this be extrapolated to an uncontrolled fire which is spreading in a shopping centre?

7. Sprinkler Effectiveness (pages 36-40)

Project 6 Report	Comments
This chapter considers the reliability and efficacy of sprinklers, how to make sprinklers more reliable, and whether sprinklers should always be required for high roof areas. It concludes that: • Sprinkler protection is critical for high levels of fire safety. • The sprinkler system required for shopping centre buildings is an Ordinary Hazard 3 system (OH3). (7.2) • In the case of high racks containing a high fire load, sprinkler heads should be located between the racks. Specific guidelines need to be developed. (7.2) • The reliability of sprinklers depends very much on how they are managed in terms of isolation of the system during building modifications. (7.3) • In Australia the efficacy of sprinklers is 97.5% based on an analysis of statistical data. This can be increased to 100% with better positioning of sprinkler heads in relation to higher racking and the absence of partial sprinklering. (7.2) • In Australia the reliability of sprinklers is 98%, based on an analysis of statistical data. This can be increased to 98.5% for speciality shops, and 99.5% for major stores with sound management of the sprinkler system. (7.3) • The use of monitored valves is an essential additional measure to guard against accidental or unintended valve isolation. (7.3) • Sprinklers will not be effective at heights greater than 10m above the closest floor level. It recommends that other strategies be developed for handling fires within malls and atrium spaces. (7.4)	The recommendation that specific guidelines need to be developed for sprinklers for the case of high racks containing a high fire load is not included in the conclusions. Despite this analysis, there is still a small probability of the sprinklers not working.

8. Fire Scenarios (pages 41-55)

Project 6 Report	Comments
A range of fire scenarios, their likelihood, and their potential impact on the occupants and the building are described. The fire scenarios are 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. *Fire brigade called*. The report assumes that 80% of fire starts will not result in a brigade attendance. These fires self-extinguish or are extinguished by the occupants and are not considered further in the report. (8.3.1) *Time of day*. USA statistics indicate that 70.4% of fires occur during the day, and these are primarily of concern with respect to life safety. Fires at night are deemed to be of greater interest for property protection. (8.3.2.1a)	

Project 6 Report	Comments
Location. The fires are grouped into locations as follows: means of egress, assembly sales, service facilities, equipment areas, structural areas and storage areas. (8.3.2.1b) *Fire size*. The fires are grouped into 3 classes: 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. (8.3.2.1d) C1 fires are small, having been limited to the area of fire origin by means of self-extinguishment or occupant and/or brigade intervention without the assistance of sprinklers. (8.3.2.2) These fires, in general, do not present a threat to the occupants. (8.4.1) C2 fires are controlled by sprinklers and are relatively small fires with low heat release rates. The smoke generating capacity of these fires is a function of the position of the sprinkler heads and the orientation and types of combustibles. (8.3.2.3) C3 fires eventuate when the sprinkler system has failed. These fires are not limited to the area of fire origin. These fires present a significant threat to the occupants. (8.3.2.4)	The threat of the C3 fire to property is not stated.
The number and type of fires are reported as being influenced by the following factors: • Monitoring of electrical switchboards. 36% of fire starts are ascribed to electrical causes and it is assumed that 50% of these could be eliminated by a 12 month inspection. • Earth leakage residual current protection. From Swiss data it is estimated that residual current protection will reduce electrical fire starts by 17.5%. • Non-combustible construction in structural areas. The report states that if non-combustible construction and materials are used, then 75% of structural fires will remain limited to the area of fire origin. Combustible construction was incorporated in parts of many of the unsprinklered shopping complexes in the USA fire data. The structural component or finish was the material ignited in 26% of these fires • Sprinkler effectiveness. This can be increased with a soundly managed sprinkler system. • Smoke detection and increased surveillance. For critical areas (particularly storage areas associated with major stores) smoke detection or increased surveillance will give an earlier warning from the sprinklers and may therefore prevent a C1 fire from increasing to a C2 or C3. • Occupant fire fighting. Improvement in occupant fire fighting is likely to result in a greater limitation of fires to the area or object of origin. (8.4.2)	No information was given to support the statements regarding the limiting of the structural fire to the area of fire origin with non-combustible construction or the ignition of the structural component.

Project 6 Report	Comments
The numbers of C1, C2 and C3 fires associated with each fire scenario group are calculated using US data. Based on these figures it is concluded that the likelihood of a C3 fire with a soundly managed sprinkler system is extremely small. Therefore, the primary design fire for these buildings, for the purpose of designing smoke management and the building structure, should be a C2 or sprinkler controlled fire. It concludes, also, that a C3 fire needs to be considered. (8.4.4)	Recommendations for monitoring of electrical switchboards, providing leakage residual current protection, and providing smoke detection and increased surveillance in critical areas are not included in the conclusions.

9.0 Building Layouts (pages 56-58)

Project 6 Report	Comments
A typical building layout is described, based on the shopping centre survey, to assist the discussion on various fire safety issues. The layouts contain the fire-isolated passages and minimum exits required by the BCA. The building contains: a mall at all levels connected by escalators/travelators, specialty shops, a multi-storey department store with internal escalators/travelators, single storey major stores, a food court in the mall, a cinema and a multistorey carpark. In this building all shops, cinemas and carparks open onto the mall at each level.	A layout of the building based on the guidelines would be useful.

10.0 Occupant Response and Movement (pages 59-72)

Project 6 Report	Comments
The response of occupants to fire cues and the time for movement to a safe place are discussed. It is assumed that the shopping centres have an Evacuation Plan and the wardens have been appointed and trained in the analysis. (10.1)	
US fire data is used to conclude that increased surveillance of ‘higher risk’ areas such as storage areas (10.2.2) and the provision of extinguishers with associated training (10.2.3) will improve fire safety in these buildings.	The increased surveillance of ‘higher risk’ areas is not included in the conclusions for the document.
From the survey of the shopping centres as reported in *Shopping Centre Review*[6] it was concluded that dense smoke is a more effective cue than an alert signal and that the natural tendency of staff is to guide people towards the major or most commonly used exits. It is also noted that in the event of a fire in the mall, the specialty shop operators may wish to evacuate their stores so that the shop front doors can be closed to minimise smoke damage.(10.3.2)	

Project 6 Report	Comments
From the available fire statistics and major fire incidents it is concluded that ‘Avoiding entrapment is of fundamental importance.’ (10.3.3) The guidelines propose that the number of occupants for the evacuation calculations is 1 per 6 m^2 for shops and 1 per 10 m^2 for the mall and upper levels with restricted access, which are half those specified in the BCA. These values were based on the weekly door count for the population flow from the one shopping centre studied in detail. The weekly door count data was reduced assuming that shoppers spend on average 2 hours in the shopping centre, based on advice that this was reasonable from the shopping centre management. 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 unlikely, and therefore the reduction in occupant load is made. (10.3.4.2) From the *Shopping Centre Review*[6] it was determined that the movement of occupants would be towards familiar exits, with the emergency exits only being used if the familiar exits were blocked. It was also determined that people would move into the mall or outside depending on the exits available and that movement would be instigated by the presence of dense smoke. (10.3.4.4) A simplified method of hand calculation is presented for the shops based on ISCUBR, RD 30[29] and the SFPE handbook[30]. An evacuation model such as EvacSim is recommended for the evacuation calculations of the shopping centre as a whole. (10.3.4.5)	Note that avoiding entrapment is important. The reduction of the population is based on the survey of one shopping centre. The guidelines say that the 2-hour average stay is based on data from the shopping centre management. The review states that the shopping centre gave advice that the number was reasonable. The review showed that if a 3-hour average stay is used the numbers go up by over half. Roof and basement carparks are not considered in the Project 6 Report, therefore their effect on occupant response (ie. occupants wanting to return to their cars) is not discussed.

11.0 Smoke Management (pages 73-104)
11.1 Introduction

Project 6 Report	Comments
The fundamental principle for the approach to smoke management in the guidelines is that ‘Entrapment of occupants should be avoided through the provision of sufficient exits (type, number and location) to allow escape from any credible threat’.	

Project 6 Report	Comments
The objectives of smoke management are defined as smoke control and evacuation of the occupants, maintaining visibility for the fire fighters and minimising property damage. The strategies for achieving these objectives include: • Keeping the fire small to keep the amount of smoke small. • Providing adequate exit paths and evacuation strategies to move people away from the smoke. • Providing sufficient smoke reservoirs to keep the smoke above the occupants. Providing adequate venting/extraction where appropriate to remove the smoke.	

11.2 Smoke associated with the fire scenarios.

Project 6 Report	Comments
Based on the statistical analysis of the fire scenarios, it was calculated that for a building with a gross lettable floor area of 75,000m^2, over a 50-year period, 800 fires would not be attended by the fire brigade and 200 would. Of the 200 fires, 141 would occur during occupied hours, 114.5 C1 fires, 26 C2 fires and less than 1 C3 fires. Based on these figures it was concluded that the primary design fire for these buildings should be a C2 (sprinklered) fire, although the impact of a C3 (uncontrolled) fire needs to be considered. (11.2.1) The volume of smoke generated from a C2 (sprinkler controlled) fire is a function of the type and arrangement of combustibles and the sprinkler arrangement in relation to the fire. The sprinklered fires are categorised in terms of racking height and sprinkler position. It is recommended that each part of the building should be designed for the category of fire likely. Smoke filling rates are given for the fire categories based on the sprinkler fire tests carried out. In deriving this data it was assumed that the smoke interface corresponded to transmissivity values of 0.5. (11.2.4) The C3 fire chosen as the design fire is based on a specialty shop with a floor area of 104 m^2, a ventilation area of 10.5 m^2 and a fire load of 450 MJ/m^2, an ultra-fast growth rate and a peak heat release rate of 40 MW. This was justified by stating that: a C3 fire is a rare event so average conditions are appropriate, this is more severe than any of the fire tests carried out and it is considerably more severe than any fire currently considered for assessing tenability of parts of the building. The heat release rate curve for the C3 design fire has a peak heat release rate of approximately 47MW at 8-9 minutes and then the heat release rate is assumed to reduce. (11.2.5)	The heat release rate reducing mean that C3 fire, unconfined and uncontrolled goes out. What stops the spread of the C3 fire and extinguishes it?

11.3 Smoke venting and exhaust.

Project 6 Report	Comments
Smoke extraction can be via venting or a mechanical exhaust system. (11.3.1) Wind and detectors for activation are identified as issues that need to be addressed in the design of a venting system. (11.3.2.1) Supply air and efficiency drops as the fans heat up are issues for the design of mechanical extraction systems. (11.3.2.2) The report *Reliability of Smoke Control Systems*[31] investigates the effectiveness of smoke exhaust systems and concludes that, assuming that average levels of commissioning and maintenance are undertaken, the effectiveness of a modern smoke exhaust/venting system is around 95%. For the remainder of the report it is assumed that these systems work. (11.3.4) The authors state that although smoke baffles may limit the extent of smoke damage, they are not necessary for an effective smoke control system. It was considered that in a C2 fire smoke would remain buoyant for a length of 60m and beyond this it would be diluted such that it would not be a threat. (11.3.2.3)	No data is given to support the smoke baffle spacing. In Sections 1 and 11.1, property protection is stated as of importance in shopping centre buildings.

11.4 Design for evacuation.

Project 6 Report	Comments
Design proposals are presented based on the following principles determined from the study of occupant behaviour and movement: • Familiar exit/entrance routes are used for evacuation paths wherever possible. • Paths should have sufficient capacity to allow for efficient movement. • Sufficient paths should be used to avoid the possibility of entrapment. • The training of wardens should be such that they have a positive impact on any evacuation. (11.4.1) The mall is deemed to be a 'safe' place provided that it has sufficient volume and/or smoke exhaust/venting to ensure that the smoke layer is maintained at an appropriate height to achieve 'infinite' tenability in a C2 (design) fire and to allow for timely evacuation in the event of the C3 fire. For the mall to be a 'safe' place, the occupants must be able to move between the levels in the mall and to connected safe places. The guidelines state that, at any level in the mall, the means of egress should: be not less than three in number, be accessible from both sides of the mall, be spaced apart not more than 75m, be provided within 20m of each end of the mall and each have an effective width of at least 1.5m. It is stated that variations from these	Timely evacuation is required in the event of a C3 fire. Visibility for fire fighters? No calculations or references are given for the derivation of these requirements.

Project 6 Report	Comments
recommendations require specific analysis. (11.4.2.1) The report recommends that upward moving escalators/travelators be stopped then reversed in the event of a C3 fire. (11.4.2.1) Carparks are deemed to be a connected 'safe' place. The report concludes that a C2 fire is likely to have little effect on the carpark, however smoke from a C3 fire could pass into the carpark. It recommends that openings not be permitted between specialty shops and the carpark and that the mall entrances be protected with closing devices activated by smoke detectors on the mall side and fast response sprinklers connected to the carpark system. Fires starting in carparks are not considered to be a problem due to sprinkler reliability, the nature of car fires and the geometry of the carparks in relation to the mall entrances. (11.4.2.2) It is recommended that the BCA requirements for egress from the shops be followed but with an exit into the mall being considered as one of the 'required' exits. (11.4.2.3) Desirable evacuation procedures are outlined. For evacuation from a major store it is stated that for the purposes 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. For the purpose of calculation of the time for evacuation of the mall, it is advised that 50% of the occupants of a major store would move into the mall and the remainder would use the emergency exits. (11.4.3) Evacuation times are calculated in accordance with Section 10 of the report with the initiation of evacuation being the presence of dense smoke ie. Evacuation time equals movement time.	The effect of the mall entrance doors closing in the event of a C2 fire is not considered. The data on which this recommendation is based is not given.

11.5 Design for Smoke Control.

Project 6 Report	Comments
The smoke control system should 'be designed taking into account the rate at which smoke is produced, the speed with which evacuation can take place and the paths likely to be followed by the smoke within that part of the building.' (11.5.1) A minimum smoke height of 2m is recommended. (11.5.1)	The effect of the temperature of the smoke layer on tenability is not considered, only the height of the smoke layer.
For sprinklered fires, a formula is derived from two of the fire tests in the experimental program giving the volume of smoke in terms of time. It is recommended that the formula be used with caution due to the limited nature of	The formula for smoke volume is recommended to be used with caution but no alternative method for calculating smoke volume is given.

Project 6 Report	Comments
the data. The shops could be designed as The smoke reservoirs, however venting or extraction is required in the malls to maintain 'safe' places, although the reservoir effects of adjacent shops can be taken into account. (11.5.2.1)	Smoke damage is not discussed in relation to these sprinklered fires.
For the C3, fire zone modelling or other formula are recommended, with the effect of the venting or exhaust within the enclosure being taken into account. (11.5.2.2)	Section 11.5.3.2 states that an exhaust system is unlikely to cope with the quantity or temperature of the smoke.
The various parts of the shopping centre are considered: • The time to untenable conditions will be greater than the evacuation time in the specialty stores. (11.5.3.1) • In a single level major store, for a C2 or C3 fire, the smoke can spill into the mall when the smoke reservoir is full, keeping the smoke layer at greater than 2m above the floor. An exhaust system can be provided, but it is unlikely that it will cope with the quantity or temperature of the smoke. (11.5.3.2) • In a multi-level department store vents at the top of the escalator shafts will ensure the smoke filling occurs from the top down and that the occupants at the levels above the fire are aware of the fire. Some level of smoke extraction may be required to clear the smoke from the major stores, but it is not regarded that it is required for life safety. (11.5.3.2)	The size the C3 fire is not stated. Smoke extraction is not required for life safety in a C3 fire?
Adequate smoke control is required for the mall to be maintained as a 'safe' place. The report recommends that venting/extraction be provided at the roof with openings provided to permit the smoke to get there. Recommendations for openings are given to achieve this. It is stated that the smoke will travel to the opening closest to the source of the smoke and the other openings will remain essentially smoke free. (11.5.3.3)	The data on which these recommendations are based is not given.

Project 6 Report	Comments
report states that the smoke extract system for the mall should be designed for the C3 fire and its capacity checked for the C2 fire. (11.5.3.3) The smoke extract system in the mall is to be designed for the most severe C2 design fire likely to be encountered in the part of the mall being considered. (11.5.3.3) In the event of a C3 fire in a major store, smoke will fill the ceiling spaces before entering the mall. 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. (11.5.3.3)	This is in contrast to Section 11.2.1 that states that the primary design fire is the C2 fire. Section 14.5.4.2 states that once the fire within the specialty store breaks through the ceiling, it can move horizontally within the ceiling space to the adjacent stores. ie. the ceiling space can contribute to fire spread. Note that combustible materials will effect the fire spread through and within the ceiling space. The smoke extract system required for large atria will have an impact on the overall design of the smoke control system for the shopping centre. This is not discussed in the Project 6 Report. Refer to the discussion on atria in Section 2.2 of this report.

11.6 Case Studies

Project 6 Report	Comments
Calculations for case studies are given based on the guidelines in the report. Dense smoke is taken as the cue for evacuation of the mall.	Will the occupants of offices and cinemas that are closed off from the mall area see the smoke? How about occupants remote from the fire origin?
The C3 design fire used in the calculations is the nominated C3 design fire from Section 11.2.5, based on a specialty shop that starts to 'go out' after 8-9 minutes.	In these examples spread of a C3 fire from the room of fire origin is not considered. The uncontrolled C3 fire goes out?
For the single level major store, the nominated C3 fire is considered to occur within a storage enclosure. The C3 fire is placed in the storage area and the interface height of the smoke in the department store is determined from the zone model.	In Section 14.5.4.2, it states that '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 heat being generated by such fires.' ie. the fire will not 'go out' as per the nominated C3 fire used in the design, but spread.

Project 6 Report	Comments
For the multilevel major store, the C3 fire is assumed to occur on the ground floor. A central escalator is modelled with a roof vent in the zone model, and the smoke interface heights are calculated at each level of the department store.	In Section 14.5.4.2, it states that between 40-100% of C3 fires that have extended beyond the room of fire origin in major stores must be assumed to have spread throughout the store. ie. the fire will not 'go out' as per the nominated C3 fire used in the design. The temperature of the smoke layer and the provision of return air and its effect on smoke flow are not discussed in the Project 6 Report. Dense smoke is taken as the cue for evacuation. No alternative alarm system to the sprinklers is recommended in the event of a sprinkler failure and a C3 fire. Smoke and fires in atriums are not addressed.

12.0 Building Structure – Fire Resistance Levels (pages 105-125)
12.1 Introduction

Project 6 Report	Comments
Section C (Fire Resistance) of BCA 96 has the following functional statement: "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 report interprets these guidelines to mean that the building structure requires a fire-resistance related to the times required for movement of the occupants to a safe place (mall, street or adjacent carpark), and not to protect the structure for its own sake.	

12.2 Consideration of Fire Scenarios

Project 6 Report	Comments
The report states ‘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 (C2 fire).’ and ‘It is also necessary to consider the impact of a non-sprinklered fire, to show that even in that situation, successful evacuation is possible.’ Fires not attended by the fire brigade are assumed to have a negligible effect on the structure. (12.2.2) Based on fire test data, C1 fires (fires kept small without sprinklers) have a negligible impact on floor and beam strength. (12.2.3)	
For fires that are controlled by sprinklers, C2 fires, the findings from the sprinklered tests as discussed in Chapter 6 of the report indicate that even lightweight members will not be significantly affected. (12.2.4)	Note that the structural materials in the fire tests were non-combustible.
C3 fires, fires that are not limited to the area of fire origin, have the most potential to impact the building structure. ‘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 the mall has been designed in accordance with the principles given in Chapter 11.’ (12.2.5.1)	There are no fire separations to prevent the fire from spreading from the room of fire origin, so the mall is not a safe place.
It is assumed that 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. As outlined in Chapter 11, it is stated that premovement time can be ignored provided the C3 fire effects are considered from the start of significant fire growth A four-storey department store, without direct horizontal access to the mall or a ‘safe place’ at each level, is considered to be the potentially most critical part of a shopping centre in terms of egress time. Calculations for the time for the last person to reach a ‘safe place’ are made for the department store assuming: • the plan area for sales at each level is 5000m^2, • there is always access at Level 1 to a safe place, • any horizontal access is 6m wide, and if it exists, all occupants will use it,	What initiates movement of the occupants not in the part of the building affected by the fire? ie. will the occupants on an upper level of a department store or in an office or cinema above the mall area have a cue to initiate movement at the start of significant fire growth?.

Project 6 Report	Comments
• that if there is no horizontal access at a level then evacuation will be by fire-isolated stairs, • the priority is to evacuate the occupants on and above the fire floor. The evacuation of the lower levels is not included in the evacuation times. The movement times are tabulated and vary between 3 and 6.15 minutes. It is stated that the fire resistance requirements should be related to these times. (12.2.5.1) It is concluded that: • 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. • 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. • Adjacent carpark levels designed as safe places should be designed such that the boundary construction provides adequate fire separation. The fire resistance 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. (12.2.5.1)	If the alarm system alerts the whole building, evacuation of the lower levels may occur. Example calculations for one building are used to propose FRLs for all buildings. There is no guidance given for calculating the FRL based on egress time. The mall is not a safe place. There is no mention of roof or basement carparks.
It is stated that when a C3 fire has spread beyond the room of origin it will be very difficult for the fire brigade to have much impact. Based on the tests these fires may be in excess of 40 MW with air temperatures exceeding 1200°C. The following facts about structures and shopping centre buildings are noted: • Movement and noise due to thermal expansion of the floor above the fire will be a reinforcing cue for initiating of evacuation. • Fires in shopping centres may have a very rapid temperature rise and very high temperatures due to the high plastics content of the combustibles. Damage to the floors above could lead to large deformations of the floor, with the load being carried by membrane action, provided there is some restraint to the members. • A local failure of a floor will not lead to collapse of the floors above, provided the structural adequacy of the columns in this fire-effected part is maintained. • Based on the longest evacuation time of 6.15 minutes, the columns at the lower levels of the building should have a FRL of 15-30 minutes. Due to the large plan area of these shopping centres, failure of a few columns will not result in collapse of the building. (12.2.5.2.2)	The C3 fire spreading beyond the room of origin is not considered in the design of the smoke management systems or evacuation Will the occupants know what the noises and movements due to the thermal expansion of the floor are? This section concentrates on structural failure. Integrity and insulation do not seem to be considered.

12.3 Lessons from Case Studies

Project 6 Report	Comments
The fire in L'Innovation in Belgium is reviewed. The building had: • 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. It was concluded that, although sections of the building collapsed during the fire, the behaviour of the building structure did not contribute to the deaths in the fire.	The building structure in an unsprinklered shopping centre did not contribute to deaths in a fire.

12.4 Current Regulatory Requirements – Implications

Project 6 Report	Comments
The BCA requirements for construction type are reviewed and shown to be dependent on the rise in storey. A comparison of the acceptable requirements with the BCA objectives is made. It is determined that 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	

12.5 Fire Resistance Levels

Project 6 Report	Comments
The recommendations in the report for a sprinklered shopping centre with a rise in storey of up to four are as follows: '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.'	It does not state why the columns need to be non-combustible. In section 12.2.5.1, it states that the fire resistance period for the boundary construction to the carpark is estimated as being less than 10 minutes.

Project 6 Report	Comments
   The BCA requirements for carparks are appropriate. These requirements can be adopted for cinemas, as the fire load will be lower than for the retail occupancies.	Is 30 minutes enough time to get people into and then out of the carpark? Note that: • The fire resistance requirements stated here are prescriptive and are based on calculations of movement times for a particular building arrangement. • Property protection is stated as an objective in Chapter 1 but it is not considered here. • Calculations for the fire resistance rating are based on movement initiated by the observation of dense smoke, with no alternative detection and alarm system. No allowance is made for delays in seeing the smoke on other levels than that of the fire origin. • No indication is given as to whether a floor should have the FRL of the column if it provides lateral restraint to it or not. • Does the structure supporting and providing lateral restraint to the fire-isolated exit stairs require a fire resistance rating? • Could smoke and fire entering the mall make the mall above impassable and thus generate longer exit times or trap occupants in the building? • Could FRL of walls and floors slow down the spread of the C3 fire, giving longer times available for evacuation, a potentially smaller fire on arrival of the fire brigade and more time for occupants in other locations of the shopping centre to escape from a potentially rapidly spreading fire? • No requirements are given for the protection of adjacent properties.

13.0 Building Structure – Other Issues (pages 126-128)

Project 6 Report	Comments
In this chapter the BCA requirements relating to fire separation of various classes of buildings, doors and separations associated with atriums are considered. The guideline states that the BCA requirement for buildings of different classification to have the highest FRL or be separated by a firewall is not required. The basis for this is that the severity of a fire associated with one part of a building is primarily a function of the fire load and the conditions in that part of the building. (13.2) The guideline recommends that shutters and doors should be avoided as they disorientate and interfere with the natural flow of the people in an emergency. (13.3) The recommendations with respect to ceiling space barriers for stopping the spread of a C3 fire are: • Provide ceiling space barriers at every 10th specialty shop or 50m whichever is closer. (13.4.1) • Provide a ceiling space barrier at the sprinkler zone junctions to reduce the likelihood of the adjacent zone being overwhelmed. (13.4.2) • Gaps around penetrations in ceiling space barriers do not need to be fire stopped but should not exceed 50mm. (13.4.3) The BCA requirements for door construction are considered to be appropriate. If the fire is adjacent to a fire isolated passage then the passage will not be used, therefore an alternative proposal for a fire resistance requirement for integrity only is suggested for these doors. (13.5) The guidelines state that a bounding wall as specified in the BCA atrium requirements will not be needed as glazing will separate the combustibles from the radiant flames and this will be protected by sprinklers and the smoke will be cooled by air entrainment. (13.6)	This assumes no combustibles will be in the mall area.

14.0 Fire Brigade Involvement (pages 129-143)

Project 6 Report	Comments
The fire brigade's charter relates to the safety of the occupants and to property protection. The ability of the fire brigade to carry out its functions is influenced by: the receiving of the alarm, activities and timing including travel and setting up times, fire brigade facilities, and the size of the fire confronted. (14.1)	

Project 6 Report	Comments
Alarms to the fire brigade can be from smoke detectors or sprinklers on a direct line, occupants activating a manual call point, MCP, or telephoning the fire brigade, occupants informing management who notify the brigade by a MCP or telephoning, or from an external observer. Shopping Centre management in the surveys have indicated that a telephone is more likely to be used than a MCP. Occupant observation and sprinklers are backed up by smoke detectors in the return air ducts if they have not been isolated. (14.2) The activities of the fire brigade were analysed and the time from the receiving of the alarm to application of water to the fire were calculated as 15 to 18 minutes for the building laid out in Chapter 9. The impact of occupant movement on fire brigade activities was not included in the calculation. (14.3) It was considered that vehicular access around the building could be replaced by adequate vehicular access to nominated major entrances with a Fire Indicator Panel at each entrance. (14.3) The fire brigade indicated that for buildings of three storeys, fire fighting would most likely be undertaken with hose reels and lines from the appliance. Internal hydrants would be used if the distance to the fire was too great for hose reels and lined to be used. (14.4.2) Spacing of internal hydrants should be determined assuming that two lengths of hose line (60m) can be run from each internal hydrant. (14.7.1) The fire brigade is responsible for the final extinguishment of a C1 and C2 fire. (14.5.2, 14.5.3) A C3 fire confined to the room of origin may need prompt action by the fire brigade to contain the fire within the room and finally extinguish it. (14.5.4.1) With a C3 fire that has extended beyond the room of fire origin, 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. (14.5.4.2) A C3 fire in a major store would be so large that the fire brigade could only attempt to prevent further spread. (14.5.4.2) For a C3 fire in a specialty shop: extinguishment of the fire in the shop of origin would be difficult. Preventing the spread of the fire to adjacent shops via the ceiling could only be attempted by wetting the combustibles in the adjacent shops. Preventing the fire spreading to shops across the mall would be attempted by cooling the facades of the opposite stores. If the occupants do not delay the fire development in some way, or if it is not a fast growing fire, then it is likely that it will be difficult for the fire brigade to have an impact. (14.5.4.2)	Note that this exceeds the proposed FRL calculated in Chapter 12. Note that the fire brigade will have difficulty having an impact on a C3 fire if its development is not delayed and can only attempt to prevent the spread of the fire.

Project 6 Report	Comments
Due to the light construction of the walls separating storage rooms from the shops, it is considered that the spread of the fire into the sales area would be rapid due to the heat being generated by the fires. (14.5.4.2) The radiation from a C3 fire will be such that the fire brigade will not be able to get sufficiently close to be threatened by deforming parts of the building structure. The greatest threat to fire fighters will be the smoke generated by such a fire. (14.6) Limiting the spread of fire may be able to be achieved by using the sprinkler systems in the adjacent zones, with the fire brigade providing the necessary means to boost the sprinkler supply. (14.6) Hydrants and sprinkler systems should not be isolated in a particular zone at one time. (14.7.2) The report states that provided Fire Indicator Panels are positioned at each major entrance, then it is difficult to see any justification for the provision of fire control centres. (14.7.5)	

15.0 Protection of Property (page 144)

Project 6 Report	Comments
The key issues in relation to property protection are given as follows: • The most effective way to protect property is to avoid fire starts. Routine maintenance and associated electrical maintenance reduce the numbers of fire starts. • Damage is minimised if the fire is confined to the object or area of fire origin. It is stated that statistics show that this very likely during the day and likely during the night. A soundly managed sprinkler system is effective in confining the fire to the object or area of fire origin. • 'High levels of structural fire resistance will not provide high levels of property protection.'	No references or data is given to support this statement regarding structural fire resistance.

16.0 Conclusions and Recommendations (pages 145-151)

<table>
<tr><td>Project 6 Report</td><td>Comments</td></tr>
<tr><td>The main conclusions for a low-rise sprinklered shopping centre building having a rise in storey of up to four are summarised as follows:
• Statistical data from USA and Australia show that shopping centre buildings do not present a significant risk to life from fire. The number of deaths and injuries increase with increasing fire size.
• More fires occur during normal operating hours and the majority of these fires are detected by the occupants and extinguished before they extend beyond the area of fire origin. (C1 fires)
• Sprinklers have a significant impact on whether fires are confined to the area of fire origin.
• A sprinkler system, soundly managed in accordance with the principles given in Section 7.3, will have an effectiveness of 98.5% for specialty shop zones and 99.5% for major store zones.
• 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.
• In the presence of a soundly managed sprinkler system, the primary design fire should be a sprinklered fire (C2 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. The margin of safety adopted when considering the C3 fire should be considerably lower than when designing the building for a C2 fire.
• Normal exit/entrance routes should be used as evacuation paths rather than fire emergency ‘passages’, as the occupants are more likely to use them. 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.
• Exits in major stores should comply with the current deemed to satisfy requirements of the BCA with the exception that the entrance to the mall is also considered an exit.
• For specialty shops, the maximum distance of travel to an exit should not exceed 20m.
• The mall is to be designed as a ‘safe place’, as in the event of a fire in a shop, people will move into the mall and then away from the fire. The mall is to be designed to have ‘infinite tenability’ in the case of the C2 fire, and sufficient normal exit paths and smoke control to allow evacuation of any level within the mall given a C3 fire.</td><td></td></tr>
</table>

Project 6 Report	Comments
• There should be an Evacuation Management Plan. Wardens should be trained such that they have a positive impact on any evacuation. • The building structure must have structural adequacy sufficient to ensure that, when subject to a C3 fire, it does not interfere with the ability of the occupants to move away from the fire. The fire resistance required should therefore relate directly to the time it takes for the occupants to move to a safe place. • Sprinklered fires have a negligible effect on the building structure. • 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. It is recommended that ceilings in malls and walkways are group D materials. (eg. Masonry, paper faced and painted gypsum plaster, some fire-retarded timbers and timber products) • Columns associated with the upper two storeys of a four storey shopping building 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. • 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. • The use of fire shutters, which close off parts of the building to restrict compartment sizes, should be avoided across circulation routes. • Basic fire fighting training and the provision of portable extinguishers and hose reels will reduce the likelihood of a C3 fire occurring during the normal operating hours of the building. • The fire brigade should have access to the major entrances to the building. • The fire safety systems should be 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 the systems. A statement or a reference to a section in the report addresses the responses to the key issues.	The fire resistance rating for the structure must be sufficient to allow evacuation in the event of a C3 fire. Ceilings in the mall must be constructed to minimise the risk of spread of flame in the event of a C3 fire. The recommendations for ceiling construction are not discussed elsewhere in the Project 6 Report. Fire resistance requirements of: Upper columns and floors - 15 mins Lower columns and walls to carparks - 30 mins Ceilings in malls to be non-combustible.

APPENDIX B
FIRE INCIDENTS IN RETAIL PREMISES

The report *Case Studies of Fires in Retail Buildings*[4] reviews and documents the fatalities in 97 fires in retail buildings. Information on the fires has been obtained from journals and it is unlikely that these fires form a representative sample from which statistically based conclusions can be made. [4] The fires from this report which occurred in buildings with combustible surface finishes, that were constructed with combustible materials, had rapid fire spread, or where the fire-rated construction failed (ie. it collapsed or the fire spread) are:

- **A L'Innovation – Brussels, Belgium, 22 May 1967**
  Five level building constructed of steel and reinforced concrete with no sprinklers or compartmentation above or below the ceiling. Combustible ceilings were present below the normal ceilings. The fire spread rapidly up an open stair and the atrium and horizontally. Parts of the building collapsed. 400 deaths.
- **Winter Park Mall – Florida, USA, 6 April 1969**
  Single storey shops of stucco covered wire lath panels on steel studs. Two, two-storey department stores at each end with concrete floors and walls and steel framed roof. Internal walls of timber stud covered with gypsum plaster board. Sprinklers in the department store and a deluge system at the glass entrance door to the mall. The fire started in the ceiling of the single storey section and spread rapidly through the ceiling space including above the deluge system. Eight stores involved. Roof over fire origin collapsed.
- **Supermarket – Europe, 1970**
  A sprinklered primarily single storey building, with a mezzanine. The fire started in an unsprinklered canopy to a hotdog stand and spread through a ventilation shaft up to the mezzanine level. The sprinkler system was activated but was overwhelmed and a large part of the building, including the roof, was destroyed.
- **Shopping Centre – Europe, 1970 or 1971**
  Unprotected steel building with storage areas sprinklered and fire-separated from the remainder of the store. The fire started in the ceiling space within the sales area. Everything was destroyed except the two storage areas. Sprinklers in the storage area did not operate as the power lines for it were destroyed in the fire in the sales area.
- **Furniture Store – Europe, 1970 or 1971**
  Four storey furniture store of fire-resistant construction with numerous fire-resistant walls. Sprinklered except in the ceiling space. The fire spread rapidly throughout the entire complex via the ceiling space and unstopped openings in fire-resistant walls.
- **Multiple Store – Bognor Regis, UK, 26 August 1976**
  Three-storey building with timber floors. The fire started in the 1st storey stock room and burnt through the timber floor to the ground level. All three storeys were severely damaged.
- **Department Store – South Glamorgan – UK, 3 December 1976**
  Three-storey department store with semi basements with walls of brick and stone and corrugated sheet metal wall extensions. The semi basement floor was concrete and the upper floors were timber. The fire was assumed to start on the upper storey and after flashover it involved the ground, first and second levels. The roof, first, second and some of the ground floor collapsed.

- **Shopping Centre – Birmingham, UK, 12 January 1977**
  52 two-storey shops connected by a roofed walkway. Shops of non-combustible construction but the canopy of the shops and the roof to the covered walkway were timber. No sprinklers. The fire started in a ground floor furniture store and spread after flashover over the walkway to an adjacent store. The roof collapsed after 20 minutes. 17 shop units became involved in the fire.
- **Covered Market and Shops – West Yorkshire, UK, 4 November 1977**
  The building had a market area of stalls surrounded at the perimeter by shops, a supermarket and a 3-storey carpark on two sides. The building was concrete and masonry with a timber roof over the market area. An electrical fault started a fire in a stall in the market area that spread to the entire market area. A LPG cylinder exploded intensifying the fire. The entire market area and its roof were destroyed.
- **Shopping Centre – Missouri, USA, 10 May 1978**
  Building of unprotected, non-combustible construction. No fire walls separating the shops. Sprinklers in the department store only. The fire in a shoe shop was contained by the fire brigade. Excessive heat in the ceiling space resulted in half of the roof and ceiling assembly of the complex collapse.
- **Shopping Centre California, USA, 17 May 1978**
  Single storey shopping centre of timber framed and stucco construction with no sprinklers. The fire started in an ice-making machine and adjacent timber stud walls were ignited. The fire spread to the ceiling where it grew as a result of the combustible insulation and suspended ceiling material. The fire spread via the ceiling space and the entire building was destroyed.
- **Shopping Mall – California, USA, 10 August 1978**
  Two-storey mall of masonry construction with a steel and timber framed roof and no sprinklers. The fire started on the first floor and spread from the first floor to the second floor ceiling space through an unprotected air conditioning duct. A section of the roof collapsed 27 minutes after the arrival of the fire brigade.
- **Department Store – Oklahoma, USA, 27 September 1978**
  The store was sprinklered and had a mezzanine of timber construction used for the storage of goods. The storage area was separated from the retail area by timber stud walls. The fire started below the mezzanine and spread to above it. During the fire, the mezzanine level partially collapsed and broke a sprinkler line feeding one head.
- **Footwear and Furniture Shop – West Yorkshire, UK, 15 February 1979**
  Ground floor furniture and first floor footwear shop. The unsprinklered building was constructed with masonry walls and a timber first floor and roof. The fire started in a ground floor display and storage area and spread to the first floor causing damage to the roof.
- **Shopping Centre – Iowa, USA, October 1979**
  A partially sprinklered single storey shopping centre with shops and a restaurant. The fire started in an unsprinklered loft area of the restaurant. A back-draft explosion occurred when the fire brigade opened doors for access, and as a result the fire spread to four other stores through the concealed ceiling space and non-fire resistant walls. The steel deck roof failed and pushed out the rear external wall.

- **Grocery Store – Quebec, Canada, October 1980**
  A shopping mall with six stores including a restaurant, connected to a grocery store. The construction was concrete block walls with outer masonry skins, with a steel deck roof on steel joists. The shopping mall was unsprinklered and had mineral fibre ceiling tiles. The grocery store was sprinklered and had a ceiling of plasterboard and decorative timber. The fire started in the restaurant and spread into the mall. 34 sprinkler heads were activated in the grocery store and they prevented the spread of the fire into the grocery store. Damage to the wooded ceilings of the grocery store was limited to scorching and blackening.
- **Floreat Forum Shopping Centre – Perth, Australia, November 1980**
  A single storey shopping centre with combustible ceiling and roof insulation. There was partial sprinkler protection to the ceiling void compartment space.
  The fire started a food store and rapidly spread into the ceiling space. A number of shops suffered damage by fire, smoke and heat. An adjoining retail store contained internal sprinklers, draft stop curtains within the ceiling space and a line of sprinkler heads outside of that barrier. This installation in the ceiling space stopped the fire from spreading into the store.
- **Multiple Retail Store – London, UK, 30 April 1981**
  An unsprinklered 3-storey building of masonry construction with part concrete and glazed roof covered with bituminous felt. The floors were of part timber and concrete on protected and unprotected columns. The ground storey was protected while the first storey was not. The fire started on the 2nd floor and spread both downwards and vertically to the roof. Internal fire fighting was difficult as walls started to crack and floor and ceilings started to collapse. One fireman died by being knocked unconscious or overtaken by flashover. The 2nd storey contents and roof were fully destroyed. Fire and collapse of members destroyed the ground and 1st floor contents. Heat, smoke and water damage occurred to adjacent residential and office buildings.
- **Shopping Mall – Missouri, USA, August 1981**
  An unsprinklered single storey shopping centre containing 27 shops constructed of timber. The fire started in one store, and when vented by the fire brigade, flashover occurred and the fire spread to 9 other stores through the concealed ceiling space.
- **Shopping Arcade – Lancashire, UK, 6 June 1983**
  An unsprinklered 3-storey shopping centre of timber construction. The fire started in the kitchen of a restaurant on the first floor. The fire grew quickly due to the large amount of timber in the construction including the wall linings. The fire destroyed the majority of the shopping centre.
- **Shopko Plaza – Wisconsin, USA, 4 July 1983**
  A single storey sprinklered shopping centre. Non-combustible construction, except for the continuous unsprinklered ceiling void spaces of combustible construction. The department store and storage areas were separated by fire walls. The fire started in and spread throughout most of the ceiling space. When the fire fell from the ceiling space to floor level, 5 sprinkler heads went off, but they were ineffective as the fire was above them. The extent of fire damage and spread was not stated, although open mesh fronts to shops allowed smoke damage to the contents of the shops.

- **Georgia Shopping Centre – Georgia, USA, 20 September 1983**
  A single storey unsprinklered shopping centre. Heavy timber construction was used over the mall area with the shop construction classified as unprotected non-combustible. The metal deck roof was supported by unprotected steel and concrete block internal walls separated the shops. The fire grew undetected and rapidly spread through the heavy timber construction of the centre, possibly through the concealed ceiling spaces.
- **Denver Shopping Centre – Denver, USA, 23 November 1983**
  A single storey shopping centre with 44 shops and a four-storey department store attached. The mall and the department store were sprinklered, with a single line of sprinkler heads provided inside the shops abutting onto the mall. The concealed spaces were not sprinklered. The walls were masonry, with steel framed structure and built up roof with timber decking. The concealed spaces contained timber furring and adhesively fixed tiles. Another layer of timber and acoustic linings was also provided in some areas, below the fixed tiles. The fire originated and spread in the ceiling space. The line of sprinklers within the shop frontages was activated, although 13 shops were destroyed and 2/3 of the centre received various degrees of smoke and heat damage. Steel trusses and columns and the concrete encased steel columns collapsed.
- **Manuka Village – ACT, Australia, 12 March 1984**
  An unsprinklered single storey shopping centre with a small mezzanine. It was brick wall construction with timber trusses supporting a concrete tile roof and a steel roof in the mall areas. The fire started in an exhaust duct to a charcoal stove and spread into the timber ceiling space and throughout the ceiling void. The entire building was destroyed.
- **Department Store – East London, Republic of South Africa, 21 May 1984**
  An unsprinklered 2-storey department store with mezzanine offices, constructed with masonry walls, concrete lower ground floor, timber mezzanine and ground floor and timber roof trusses. The fire started in an electrical storeroom on the ground floor and the entire store was destroyed. There was a lack of fire detection, alarm and evacuation plan, which caused slow fire fighting and evacuation response. The evacuation from the mezzanine was slow. Five people were killed. Minimal compartmentation and internal construction of combustible material allowed fast fire spread.
- **Furniture Store – Maryland, USA, 22 October 1984**
  An unsprinklered 3-storey main building with a 2-storey extension constructed with steel framed and masonry walls with timber columns and stud walls and timber floors and roof. The fire started after the oxy-cutting of metal bolts on the 3rd storey of the main building. It spread through ventilation openings within the 2nd and 3rd floors. The fire brigade missed the 3rd floor, so while they extinguished the fire on the 2nd floor the fire worsened and spread to the extension part of the building. A flashover across combustible ceiling tiles resulted in rapid fire spread from the front to the rear of the building, killing three fire fighters. Sections of the roof and the front external wall of the building collapsed.
- **Shopping Centre – Illinois, USA, September 1985**
  Single story timber framed construction, sprinklered shopping centre. The fire started in a wooden framed external canopy. When the canopy collapsed and broke the shop window, 14 sprinkler heads operated and inhibited the spread of the fire.

- **Shopping Centre – Liverpool, UK, 24 February 1987**
  A single storey unsprinklered complex with external concrete block walls and a felt and tile pitched steel and timber roof. The internal walls between the shops were constructed to the underside of the roof, but the timber framed canopy at the shop fronts provided a continuous void. The fire was arson and started under a walkway outside the supermarket. The fire spread to 14 of the 15 other shops, extensively damaged the supermarket and destroyed the roof.
- **Shopping Mall – Wisconsin, USA, 1988**
  Sprinklered single storey complex of non-combustible construction except for the unsprinklered timber framed concealed ceiling space. The fire started due to an electrical fault in a neon sign that ignited combustibles in a wall space. The fire spread to the concealed ceiling space. The air-handling unit spread the fire through the roof space. The sprinklers activated as the fire dropped through the ceiling. Extent of damage is unknown.
- **Shopping Mall – Tennessee, USA, 1988**
  An unsprinklered 2-storey timber framed shopping mall with masonry walls. The fire stated on the 2nd floor. One occupant became trapped, was overcome by smoke and died.
- **Furniture Store – California, USA, 4 April 1988**
  An unsprinklered single storey mall of timber construction with a concealed ceiling space connecting all occupancies. The fire started due to an electrical short circuit in the ceiling space and spread via the ceiling space to all 5 occupancies. The ceiling roof and mezzanine collapsed.
- **Grocery Store – New York, USA, 4 July 1988**
  An unsprinklered single storey mall of unprotected construction. The fire started in the loading area of a store and spread rapidly through the concealed ceiling spaces to the rest of the mall. The entire mall was affected except for an area at the far end of the mall which was separated by a fire wall.
- **Shopping Mall – Nevada, USA, 20 September 1988**
  An unsprinklered mall of timber construction, containing 8 stores. The fire started in an attic space. A fire wall in the attic provided fire separation. Radiant heat transfer through the wall heated combustibles on the other side of the wall. As a result, the front mansard roof collapsed and allowed the fire to spread around the fire wall. The extent of the fire damage was not stated.
- **Shopping Mall – Florida, USA, 1989**
  A sprinklered single storey centre with an unsprinklered exterior walkway constructed of timber with plywood on cedar roof supports. The fire started in a trash can under the external walkway and spread vertically to the walkway roof and timber shingle cladding to concrete block wall. The exterior of the building was damaged and 80% of the walkway was destroyed.
- **Shopping Centre – Wiltshire, UK, 6 August 1989**
  2-story building with shops on the ground floor and shop storage and residential units on the first floor. The building was unsprinklered and of non-combustible construction except for the timber trussed roof. The fire started in a shop and spread via ceiling vents into the roof space. The use of bituminous felt in parts of the roof allowed for rapid fire spread within the timber roof space and over separating walls, igniting adjoining roofs. 4 shops were totally destroyed, the roof collapsed and there was fire damage to the other occupancies.

- **Shopping Mall – Washington State, USA, 1990**
  Unsprinklered 2-storey centre of non-combustible construction. The fire started in the restaurant and was prevented from spreading to the adjoining store by a 2 hour fire wall. A 1 hour fire wall collapsed leading to the spread of the fire into the ceiling space above a suspended ceiling. The restaurant roof eventually collapsed.
- **Supermarket – Massachusetts, USA, 1990**
  Sprinklers extinguished the fire in the rear storeroom of the 2-storey timber construction grocery store.
- **Department Store – Osaka, Japan, 18 March 1990**
  The fire started in the bedding department on the 4th floor of the 5-storey department store. The contents contributed to quick fire spread and smoke production. 15 occupants of the 5th floor were asphyxiated by smoke.
- **Department Store – Essex, UK, 19 August 1990**
  2-storey department store near completion in a shopping complex (6375 m^2 per storey). It was constructed of concrete floors, metal deck roof and plasterboard internal walls, and the sprinklers were not operational at the time of the fire. The fire spread rapidly through the timber, plastic and cardboard shop fittings. 50% of the ground floor was destroyed, with smoke and heat damage to the remainder of the floor. 10% of the 1st floor and roof were damaged.
- **Shopping Mall – New York, USA, 1991**
  Single storey mall containing 80 shop and 2 department stores with partial sprinkler protection within the walkway and department stores. There were no doors or glazing between the walkway and stores. The fire was kept to the store of origin by the fire brigade. The mall was evacuated within minutes but 2 people still died of smoke inhalation.
- **Shopping Mall – Long Island, USA, 16 May 1991**
  The fire started on the ground floor of a 2-storey department store attached to a single storey mall. The department was of non-combustible construction and had sprinklers in the basement. The fire brigade contained the fire in the ground floor and basement of the department store. 2 employees were killed. The fire alarm sounded in the mall but it was stated that occupants only started to evacuate when smoke entered the mall.
- **Department Store – California, 1993**
  Sprinklers in a single storey timber framed construction department store extinguished a fire.
- **Dusseldorf Airport – Dusseldorf, Germany, 11 April 1996**
  Welding work ignited bitumen, which flowed down into the ceiling above a flower shop. The airport was fire-resistant construction with sprinklers only in the kitchen and restaurant. Fire and smoke spread throughout the building via combustible cabling and air ducts. 16 people died of smoke inhalation.