ABSTRACT:

This paper presents a performance-based design for a hypothetical case study of a 4-storey shopping centre that contains malls, specialty shops, major stores, food-court, cinemas, atrium and interconnecting floor voids.

The design strategy was developed utilising:
- The research findings and recommendations of the Fire Code Reform Centre Project 6 for shopping centres.

The design strategy to achieve the fire safety objectives for the case study includes the following key elements and measures:
- A sound fire safety management of the building to control fire start and occupant evacuation.
- An effective sprinkler system to control the fire growth in the building.
- A reliable natural smoke venting system at the roof to allow smoke to vent from shopping centre through the interconnecting floor voids. Mall is therefore designed as a safe place.
- Use of normally used circulation paths, external open stairs and escalators for egress purposes.
- Staged evacuation of the mall to minimise business disruption.
- Shutters to the entries of the majors and cinema complex designed to prevent smoke spread.

In order to evaluate the performance of the proposed design against each of the fire safety objectives, fire and evacuation modelling of the shopping centre were conducted. The modelling and analysis results are presented.

In this paper, it is demonstrated that each of the design brief objectives including, occupant safety, fire brigade safety, minimising fire and smoke spread; and minimising business disruption is achieved.
1 INTRODUCTION

This paper presents a performance-based fire safety design of a hypothetical case study. The
design brief for one of three case studies formulated by the SFPE International Conference
organiser and is provided to representatives of various countries participating in the
conference so that they may each formulate a performance-based design.

This paper presents a design that represents the participation from Australia.

1.1 The Case Study Design Brief

The case study is for a 4-storey shopping centre which contains malls, specialty shops, major
stores, food-court, cinemas, atrium and interconnecting floor voids.

The performance-based fire safety analysis and design is to meet the following fire and life
safety goals:

1) Safeguard occupants from injury due to fire until they reach a safe place.
2) Safeguard fire fighters whilst performing rescue operations or attacking the fire.
3) Minimise smoke and fire spread inside the building.
4) Limit the impact on business continuity.

The initial shopping centre case study building section and floor plans as identified in the
project brief are shown in the following figures.

![Figure 1 Case Study – Building Section](image-url)
Figure 2  Case Study – Building Layout
2 PERFORMANCE-BASED DESIGN IN AUSTRALIA

2.1 Background

Performance-based fire safety design for buildings was formally introduced exactly 20 years ago in the Building Code of Australia 1996 (BCA 96).

BCA 96 was launched subsequent to a major research program by the Fire Code Reform Centre (FCRC) which was established in 1994 as a joint initiative between the Australian Government, industry and research organisations. Its mission was to develop a cost-effective, engineered approach to fire safety design and reform the building code based on similar principles. It contained 6 projects as follows:

- Project 1: Restructure the BCA Fire Provisions
- Project 2: Fire Performance Requirements for Lining Materials
- Project 3: Fire Resistance and Non-Combustibility Requirements
- Project 4: Alternative Fire Safety System Design Solutions for the BCA
- Project 5A: Fire Engineering Guidelines
- Project 5B: Fire Safety Design Code
- Project 6: Fire Safety in Low-Rise Shopping Centres

These 6 projects played a significant part in forming the BCA as it currently stands today. Much of the performance-based design approach currently used in Australia is the outcome of the FCRC Projects.

2.2 This Case Study

For the case study in this paper, the current BCA together with the methodology and findings of the FCRC are utilised, in particular Projects 5A and 6, to demonstrate the performance based design approach in Australia. 3 major sets of documents are referenced.

<table>
<thead>
<tr>
<th>Document</th>
<th>Relevance</th>
</tr>
</thead>
<tbody>
<tr>
<td>BCA 2016</td>
<td>This is the latest building code in Australia which continues the performance design approach introduced in BCA 96. In this case study, the Objectives and Performance Requirements of the BCA, together with the Design Brief objectives, will form part the basis of the building design. The prescriptive design for the case study is also discussed.</td>
</tr>
<tr>
<td>FCRC 5A (IFEG)</td>
<td>The International Fire Engineering Guideline (IFEG) 2005 is the main guidance document for fire engineering design in Australia. It is a revision of the original Fire Engineering Guideline developed in the FCRC Project 5A. In this case study, the fire safety sub-systems outlined in IFEG are used as the framework to develop the design strategy.</td>
</tr>
<tr>
<td>FCRC 6</td>
<td>FCRC Project 6 (FCRC Project 6) relates to fire safety design of shopping centres specifically and is directly related to the case being studied. In this case study, the research findings and recommendations of FCRC Project 6 are used in the design of the shopping centre.</td>
</tr>
</tbody>
</table>
3 FIRE SAFETY OBJECTIVES AND DESIGN APPROACH

3.1 Fire Safety Objectives

In Australia, buildings must be designed and constructed in accordance with BCA which contains a uniform set of technical provisions for the design and construction of buildings. For the purpose of this case study, BCA 2016 [1] is referenced.

The objectives for design for fire safety set out in the BCA may be summarised in the figure below.

A comparison of the Design Brief and BCA objectives are given below.

<table>
<thead>
<tr>
<th>Design Brief Objective</th>
<th>BCA Objective</th>
<th>Comparison</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Safeguard occupants</td>
<td>1. Safeguard occupants</td>
<td>Objective is the same</td>
</tr>
<tr>
<td>2. Safeguard fire fighters safety</td>
<td>2. Facilitate fire fighting</td>
<td>BCA objective is less demanding and would result in a less onerous design outcome</td>
</tr>
<tr>
<td>3. Minimise smoke and fire spread inside building</td>
<td>3. Avoid fire spread between buildings</td>
<td>Protection against content or building damage (other than adjacent buildings) and business continuity are not a BCA objective. The BCA objectives are less demanding and would result in a less onerous design outcome</td>
</tr>
<tr>
<td>4. Limit impact on business continuity</td>
<td>4. Avoid damage to adjacent buildings</td>
<td></td>
</tr>
</tbody>
</table>

An overall comparison shows that the Design Brief Objectives are more demanding than the BCA Objectives and would result in a more onerous design outcome.

In this paper, Design Brief Objectives are used as the basis for evaluation of the performance of the case study. Given that there is no adjacent building located in the vicinity of the shopping centre, BCA Objective 3 and 4 need not be considered. Hence, it can be regarded that BCA Objectives are achieved when the Design Brief Objectives are satisfied.
3.2 Solution Approaches

The BCA sets out *Performance Requirements* that building solutions must comply with. The compliance of *Performance Requirements* may be achieved by means of a Performance Solution or a Deemed-to-Satisfy (DtS) Solution as shown in the figure below.

![BCA Compliance Diagram](image)

*Figure 4  BCA Compliance*

In this paper, for the sake of simplicity, the *Performance Requirements* of the BCA will not be further discussed; rather, they are considered to be fully encompassed by the design objectives. The proposed solution is considered acceptable if it is demonstrated to satisfy the fire safety objectives discussed in the previous section.

Thus, the evaluation of the proposed design will be presented later in this paper against the design objectives, as opposed to against the *Performance Requirements*, as those typically carried out in the performance-based designs of buildings in Australia.

3.2.1 Performance Solution

Performance solution for the case study is the subject of this paper. It will be further discuss later in this paper.

3.2.2 BCA DtS Solution

It is noted that the shopping centre for this case study cannot be readily designed to fully comply with the BCA DtS requirements. This is particularly so for the floor voids which would be subjected to the BCA requirements for atrium construction. This would require the floor voids to be omitted or significantly modified.

Nevertheless, some of the general BCA DtS requirements for the building are outlined below. Specific aspects in relation to BCA Prescribed Solutions in relation to this case study are also discussed.

This building is considered to be a mixed-class building containing retail (Class 6) and cinemas (Class 9b), having a rise of storeys of 4, containing atria and is a large isolated building. It is required to be of Type A construction, which is the most fire resistive of the three types (A, B and C) nominated in the BCA.

The key requirements and BCA parameters pertaining to this case study are summarised in the following table.
<table>
<thead>
<tr>
<th>Fire Safety Systems</th>
<th>Governing Building Parameters</th>
<th>BCA DtS Requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Fire Resistance</strong></td>
<td>Building Class = 6 (retail) and 9b (cinemas) Rise in storeys = 4</td>
<td>Type of construction = A Min FRL = 180/180/180 (class 6) Min FRL = 120/120/120 (class 9b)</td>
</tr>
<tr>
<td><strong>Compartmentation</strong></td>
<td>Total floor area = 76,276 m² Large isolated building Building classes requiring different FRLs</td>
<td>Perimeter vehicular access Fire separation of classes</td>
</tr>
</tbody>
</table>
| **Egress** | Population (3m²/person ground level, 5m²/person upper levels)  
- L0 = 27,014 m² = 9,005 persons  
- L1 = 21,072 m² = 4,214 persons  
- L2 = 16,040 m² = 3,208 persons  
- L3 = 11,025 m² = 2,205 persons  
- Cinema Theatres (1,125m²) = 960 persons  
- Total = 19,592 persons | Min fire isolated exits per floor = 2 Min total exit width  
- L0 = 61 m  
- L1 = 29 m  
- L2 = 22.5 m  
- L3 (including cinema) = 22 m  
Max travel distance:  
- to point of choice = 20 m  
- to an exit = 40 m  
- between exits = 60 m  
- to exit via open stairway = 80 m  
Exit signs and emergency lighting |
| **Fire Fighting** | Containing enclosed mall Atrium connecting 4 levels Stairways connecting 4 levels | Sprinklers Hydrants Hosereels Portable fire extinguishers Sound System and Intercom System for emergency purposes (SSIS) |
| **Smoke management** | Enclosed mall Length of mall > 60 m Major store >1000 m² Floor levels connected by atrium = 4 | Smoke detection system Mall smoke exhaust, baffle at 60 m intervals Major store smoke exhaust Atrium smoke exhaust Stairway pressurisation Backup power supply |
| **Atrium** | Floor levels connected by atrium = 4 | Atrium well = min 6 m diameter Bounding construction Protection of atrium roof |

**Figure 5** General BCA DtS Requirements
4 AUSTRALIAN RESEARCH ON FIRE SAFETY OF SHOPPING CENTRES

4.1 Fire Code Reform Centre Project 6

In 1994-1996, a two-year intensive research (FCRC Project 6) was conducted to study all significant aspects relating to fire safety in shopping centres. The purpose of the project was to review the requirements in the BCA which apply to low-rise sprinklered shopping centres and to propose a more rational set of fire-safety requirements to improve the cost effectiveness of these buildings (both in terms of construction costs and maintenance in operation) whilst maintaining the current high levels of fire safety.

FCRC Project 6 involved various parts, including:

- review of BCA fire safety requirements for shopping centres [4]
- survey of shopping centres [5]
- case studies of retail fire incidents [7]
- review of retail fire statistics [8]
- identification of key issues [6]
- fire testing [9]
- study of behaviour of building occupants
- study of reliability of smoke control systems [10]

Some key findings of the projects are outlined below.

4.2 Shopping Centre Survey

In ref [5], a comprehensive study of a major shopping centre in Australia was carried out over a continuous two month period. Information was also collected through visits to eleven shopping centres. The centre subjected to the comprehensive study had a gross retail area of 58,000 m² having a department store with a rise in storeys of 4 at one end of a two storey mall and was considered to be representative of a large modern shopping centre. The other centres had rise in storeys of up to 5, and with one exception, had floor areas which were similar or greater than that associated with the centre used for the detailed study.

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

4.3 Case Studies

In ref [7], 97 accounts of fires in retail and shopping centre buildings, as reported in the literature, were analysed. It revealed a number of apparent trends and the following tentative observations can be made:

- The majority of fires appear to have been started by electrical faults or arson.
- In the majority of situations fires only developed to a significant size if the fire was initiated in unpopulated areas (eg. storage areas or ceiling spaces) or when the building was unoccupied.
- A major mechanism of fire spread to other parts of the building appears to have been through the ceiling space.
- Partial sprinklering is a dangerous practice which can lead to the centre being effectively destroyed.
4.4 Fire Statistics

In ref [8], the statistical data on USA retail fires attended by the fire brigade were analysed. These data, contained in the NFIRS database, includes 10 years (1983 to 1993 excluding 1986) of data and represents 77,996 retail fires. A further study was carried out on data available from Australia. A comparison of the data indicates that similar trends are demonstrated between the USA and Australian data.

The statistical data shows that fire in retail premises does not present a significant risk to life. There were 86 deaths in 77,996 retail fires over 10 years in the USA.

4.5 Fire Tests

In ref [9], eleven full-scale fire tests were conducted to investigate the effects of fires in specialty shops and major stores in a shopping centre.

![Figure 6](image)  
*Figure 6  Full-Scale Fire Tests to Simulate Shopping Centre Fire*

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

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

The heat release rate obtained from an unsprinkled fire test (Test 4) for a specialty shop is shown in the figure below.

![Figure 7](image)  
*Figure 7  Heat release rate obtained from an unsprinkled fire test*
For the purpose of this case study, fire sizes are assumed as follows:

- C2 fire in retail enclosure (specialty shop or major store) = fast $t^2$ fire plateaus at 2.0 MW
- C2 fire in mall area (atrium void) = fast $t^2$ fire plateaus at 5 MW
- C3 fire is considered to be the unsprinklered fire in a specialty as shown in the figure above (maximum heat release rate of 46.5 MW)

### 4.6 Behavioural Study

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

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

### 4.7 Final report

A final report [11] was published as an FCRC document, summarises the research and systematically evaluates fire-safety aspects of shopping centre buildings making recommendations for the design of such buildings.

Since that time, further evaluation and testing have been conducted and the design principles and procedures given in the above publications have been extended and published in [12].

The findings and recommendations from FCRC 6 and [12] are utilised in this paper to formulate the performance-based solution for the case study. This is discussed in the next section of this paper.
5 PROPOSED PERFORMANCE SOLUTION

5.1 Design Strategy

The IFEG defines fire safety of buildings to comprise six sub-systems (SS) as follows:

- **SS-A** - Fire Initiation and Development and Control
- **SS-B** - Smoke Development and Spread and Control
- **SS-C** - Fire Spread and Impact and Control
- **SS-D** - Fire Detection, Warning and Suppression
- **SS-E** - Occupant Evacuation and Control
- **SS-F** - Fire Services Intervention

For this case study, the IFEG sub-systems are used as the framework for developing the design strategy to fulfil the Design Brief and BCA fire safety objectives for the building. This is summarised in the following table.

<table>
<thead>
<tr>
<th>Sub-system</th>
<th>Design Strategy</th>
<th>Applicable Objective</th>
</tr>
</thead>
</table>
| **SS-A**   | - To minimise the number of fire starts.  
- To extinguish any fire before it becomes threatening. | Design Brief  
BCA |
| **SS-B**   | - To maintain egress paths tenable for occupants to move to place of safety  
- To limit smoke spread to minimise business disruption |  
| **SS-C**   | - To maintain structural stability for occupants evacuation and brigade fire fighting  
- To limit spread to minimise business disruption (Design Brief objective)  
- To prevent fire spread between buildings |  
| **SS-D**   | - To provide early fire detection and occupant warning.  
- To enable early fire suppression or control. |  
| **SS-E**   | - To provide means for safe egress of occupants put at risk by a fire |  
| **SS-F**   | - To provide early brigade notification  
- To provide sufficient means of fire fighting for fire brigade  
- To safeguard fire fighters |  

11
5.2 Design Principles
Design principles were developed utilising the research findings of FCRC 6 and are summarised in the table below.

<table>
<thead>
<tr>
<th>Sub-system</th>
<th>Design Principles</th>
</tr>
</thead>
</table>
| SS-A       | • Specific management plans and procedures are to be put in place by the shopping centre management to control the use and activities within the building.  
• Sufficient fire extinguishers are to be provided for occupants to fight small fires within the retail areas. |
| SS-B       | • In the event of a sprinkler controlled fire (C2) anywhere in the centre:  
  o all main egress paths in the centre are to remain tenable indefinitely.  
  o smoke spread is limited.  
• In the event of sprinkler controlled fire (C2) in a major store or the cinema complex:  
  o the smoke produced is to be limited from spreading into the adjoining mall.  
• In the event of an unsprinkler controlled fire (C3) in the centre:  
  o all main egress paths are to remain tenable for the expected duration of evacuation using the paths. |
| SS-C       | • Spread of fire from the area or enclosure of fire origin is to be prevented.  
• Collapse of multi-level building structure is to be prevented. |
| SS-D       | • Sufficient means of detection and warning the occupants are to be provided throughout the building.  
• The sprinkler system is to be reliable and commensurate with the hazard. |
| SS-E       | • The design population density is at least 10m²/person.  
• The mall area is to be a safe place for occupants to move away from the fire and to provide the primary means of escape.  
• All major access paths in the mall are to be utilised as egress paths.  
• All enclosures and areas within the centre are to be designed to avoid entrapment and have sufficient egress paths to move to a safe place, open space, or roadway, prior to the achievement of untenable conditions.  
• An evacuation plan is to be developed and implemented by the building management.  
• Evacuation of the centre is to be controlled by building management through a warden system. |
| SS-F       | • Sufficient means of notification of a fire is to be provided.  
• Sufficient fire brigade access to the building and the relevant part of the building is to be provided.  
• Sufficient communication within the building is to be provided.  
• Sufficient hydrants are to be provided and suitably located to facilitate brigade fire fighting. |
5.3 Design details
Design details and the corresponding rationale are given in Appendix A and some key details are shown below.

Egress

*Figure 8 Proposed Egress Provisions*

- **L3**: Entry to cinema complex and all major stores to have shutter automatically descend to 2 m to prevent smoke spread and allow occupants to move into mall area.

- **L2**: Mall space on each level is designed as a safe place for evacuation.

- **L1**: Use of open external stairways as primary egress routes.

- **L0**: Use of internal escalators or open stairways for movement between floors.

- **All stores and shops at perimeter of building on L0 are to have direct exits to the outside.**
Evacuation zoning

**Figure 9**  Mall Space Evacuation Zones

Natural Smoke Venting of Atrium Space

**Figure 10**  Natural Smoke Venting at Roof Level
## 5.4 Comparison of DtS Solution and Proposed Performance Solution

<table>
<thead>
<tr>
<th>Fire Safety Systems</th>
<th>BCA DtS Solution</th>
<th>Proposed Performance Solution</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Fire Resistance</strong></td>
<td>Type of construction = A</td>
<td>Type of construction = A</td>
</tr>
<tr>
<td></td>
<td>Min FRL = 180/180/180 (class 6)</td>
<td>Max FRL = 60/60/60 (throughout)</td>
</tr>
<tr>
<td></td>
<td>Min FRL = 120/120/120 (class 9b)</td>
<td></td>
</tr>
<tr>
<td><strong>Compartmentation</strong></td>
<td>Perimeter vehicular access</td>
<td>Perimeter vehicular access (No fire compartmentation)</td>
</tr>
<tr>
<td></td>
<td>Fire separation of classes</td>
<td></td>
</tr>
<tr>
<td><strong>Egress</strong></td>
<td>Min fire isolated exit per floor = 2</td>
<td>Exits distributed evenly throughout</td>
</tr>
<tr>
<td></td>
<td>Min total exit width:</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• L0 = 61 m</td>
<td>Total exit width:</td>
</tr>
<tr>
<td></td>
<td>• L1 = 29 m</td>
<td>• L0 = 44 m</td>
</tr>
<tr>
<td></td>
<td>• L2 = 22.5 m</td>
<td>• L1 = 14 m</td>
</tr>
<tr>
<td></td>
<td>• L3 (including cinema) = 22 m</td>
<td>• L2 = 13 m</td>
</tr>
<tr>
<td></td>
<td>Max travel distance:</td>
<td>• L3 = 9 m</td>
</tr>
<tr>
<td></td>
<td>• to point of choice = 20 m</td>
<td>Max travel distance:</td>
</tr>
<tr>
<td></td>
<td>• to an exit = 40 m</td>
<td>• to point of choice = 65 m</td>
</tr>
<tr>
<td></td>
<td>• between exits = 60 m</td>
<td>• to an exit = 120 m</td>
</tr>
<tr>
<td></td>
<td>• to exit via open stairway = 80 m</td>
<td>• between exits = 130 m</td>
</tr>
<tr>
<td></td>
<td>Exit signs and emergency lighting</td>
<td>• to an exit via open escalators = 260 m</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Exit signs and emergency lighting</td>
</tr>
<tr>
<td><strong>Fire Fighting and</strong></td>
<td>Sprinklers</td>
<td>Sprinklers</td>
</tr>
<tr>
<td><strong>Suppression</strong></td>
<td>Hydrants</td>
<td>Hydrants</td>
</tr>
<tr>
<td></td>
<td>Hosereels</td>
<td>(no hosereels)</td>
</tr>
<tr>
<td></td>
<td>Portable fire extinguishers</td>
<td>Portable fire extinguishers</td>
</tr>
<tr>
<td></td>
<td>SSIS</td>
<td>SSIS</td>
</tr>
<tr>
<td><strong>Smoke Management</strong></td>
<td>Smoke detection system</td>
<td>Smoke detection system</td>
</tr>
<tr>
<td></td>
<td>Major store smoke exhaust</td>
<td>Major store smoke exhaust</td>
</tr>
<tr>
<td></td>
<td>Mall smoke exhaust</td>
<td>Mall natural smoke venting</td>
</tr>
<tr>
<td></td>
<td>Mall baffle at 60 m intervals</td>
<td>Mall (no baffles)</td>
</tr>
<tr>
<td></td>
<td>Atrium smoke exhaust</td>
<td>Atrium natural smoke venting</td>
</tr>
<tr>
<td></td>
<td>Stairway pressurisation</td>
<td>(no stairway pressurization)</td>
</tr>
<tr>
<td></td>
<td>Backup power supply</td>
<td>(no backup power supply)</td>
</tr>
<tr>
<td></td>
<td>Smoke baffles or smoke curtain/shutter to descend to 2m above</td>
<td></td>
</tr>
<tr>
<td></td>
<td>to the floor at the entrance to the major stores and cinema</td>
<td></td>
</tr>
<tr>
<td></td>
<td>complex</td>
<td></td>
</tr>
<tr>
<td><strong>Atrium</strong></td>
<td>Atrium well = min 6 m diameter</td>
<td>(no min atrium dimension)</td>
</tr>
<tr>
<td></td>
<td>Bounding construction</td>
<td>(no bounding construction)</td>
</tr>
<tr>
<td></td>
<td>Protection of atrium roof</td>
<td>(no protection of atrium roof)</td>
</tr>
</tbody>
</table>
6 EVALUATION AGAINST OBJECTIVE 1 – OCCUPANT SAFETY

6.1 General

In order to evaluate the building with respect to occupant safety, the Proposed Design, as outlined in the previous section, is modelled using computer programs to simulate the occupant movement and conditions of the building, particularly the mall spaces, during various fire scenarios in the building.

The results of the computer analyses are used to determine two time periods for various fire scenarios, namely:

- Available Safe Egress Time (ASET)
- Required Safety Egress Time (RSET)

Safety of the occupants is achieved if ASET is greater than RSET, i.e.

\[ \text{ASET} > \text{RSET} \]

The above means that the occupants are able to move to a place of safety before the building becomes untenable.

For the Proposed Design, the occupants in the centre are not expected to be exposed to the fire environment for a significant period of time; and the main egress paths in the building can be considered tenable under the following conditions [17], [18]:

![Figure 11: Tenability Criteria](image)

It is noted that, at air temperatures below 100°C, the radiation will be less than 2.5 kW/m$^2$.

Margin of safety of the design is the difference between the ASET and RSET, i.e.:

\[ \text{Margin of safety} = \text{ASET} - \text{RSET} \]
6.2 ASET Analyses

The conditions within the building are examined using the computer program FDS [13], which is a Computational Fluid Dynamics (CFD) model of fire-driven fluid flow and is specifically developed for high-level fire engineering analyses. The software solves numerically a form of the Navier-Stokes equations appropriate for low-speed, thermally-driven flow with an emphasis on smoke and heat transport from fires.

6.2.1 FDS models

For the purpose of the evaluation, a 3-D computer model was constructed and is shown in the figure below. A grid size of 1m x 1m x 1m was used.

![Figure 12 FDS Model](image)

The model includes four floor levels, the floor voids connecting the floor levels, the proposed smoke vents and make-up air openings for the mall area.

In order to monitor the conditions within the building during the fire, measurement devices are placed along the main egress paths at a height of 2 m above the floor on each level within the models. These include devices to measure air temperatures, CO level, radiant heat and visibility.

6.2.2 Scenarios examined

A total of 6 base-case fire scenarios and 4 sensitivity scenarios were examined for the proposed design.

<table>
<thead>
<tr>
<th>Fire Scenario</th>
<th>Floor Level</th>
<th>Fire location</th>
<th>Fire</th>
<th>Max HRR (MW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>FS01</td>
<td>Level 0</td>
<td>1 (mall)</td>
<td>C2</td>
<td>5.0</td>
</tr>
<tr>
<td>FS02</td>
<td>Level 0</td>
<td>2 (mall)</td>
<td>C2</td>
<td>5.0</td>
</tr>
<tr>
<td>FS03</td>
<td>Level 0</td>
<td>3 (major store)</td>
<td>C2</td>
<td>2.0</td>
</tr>
<tr>
<td>FS04</td>
<td>Level 0</td>
<td>4 (specialty shop)</td>
<td>C2</td>
<td>2.0</td>
</tr>
<tr>
<td>FS05</td>
<td>Level 0</td>
<td>5 (specialty shop)</td>
<td>C2</td>
<td>2.0</td>
</tr>
<tr>
<td>FS06</td>
<td>Level 3</td>
<td>6 (Cinema)</td>
<td>C2</td>
<td>5.0</td>
</tr>
</tbody>
</table>
### Table 2  Fire Scenarios Examined (sensitivity cases)

<table>
<thead>
<tr>
<th>Fire Scenario</th>
<th>Floor Level</th>
<th>Fire location</th>
<th>Fire</th>
<th>Max HRR (MW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>FS04-a</td>
<td>Level 0</td>
<td>4 (specialty shop)</td>
<td>C2</td>
<td>5.0</td>
</tr>
<tr>
<td>FS04-b</td>
<td>Level 0</td>
<td>4 (specialty shop)</td>
<td>C3</td>
<td>46.5</td>
</tr>
<tr>
<td>FS05-a</td>
<td>Level 0</td>
<td>5 (specialty shop)</td>
<td>C2</td>
<td>5.0</td>
</tr>
<tr>
<td>FS05-b</td>
<td>Level 0</td>
<td>5 (specialty shop)</td>
<td>C3</td>
<td>46.5</td>
</tr>
</tbody>
</table>

#### Figure 13  Assumed Fire Locations

The following conservative assumptions are made in the analyses:

- Fire is only considered to occur in one location at any time.
- Fire burns for a period of 1800 s without intervention.
- Fast response sprinkler heads (activation temperature of 68°C and maximum RTI of 50 m$^{3/2}$/s$^{1/2}$) are installed as per AS 2118.1.
- Smoke detection is provided as per BCA mall space requirements (15 m apart and 7.5 m from walls, bulkheads or curtains).
- Smoke detection is provided within major stores and cinemas as per AS 1668.1 spacing requirements (20 m apart and 10 m from walls).
- All natural vents in the mall space operate on General Fire Alarm.
- Mechanical smoke exhaust of 32 m$^3$/s provided in each major store and activates 30 s after the detection of smoke in the store.
- Cinema natural vents activates after the detection of smoke in the cinema complex.
- Smoke curtains at the mall entrance to the cinema complex and to the majors drops to 2m above the floor upon detection of fire.
Each scenario was analysed for a duration of 1800 s, by which time all occupants would have moved out of the building (see following section).

6.2.3 Analysis results

The primary results of the analyses are summarised in Appendix C. The three numbers in each cell in the table correspond to the maximum air temperatures, maximum CO levels and the minimum visibility, recorded over the analysis period for the relevant floor level and fire scenario (see example below).

<table>
<thead>
<tr>
<th>Fire Scenario</th>
<th>max temperature, max CO, min visibility (°C, ppm, m)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>L0</td>
</tr>
<tr>
<td>FS01</td>
<td>20,0,30</td>
</tr>
<tr>
<td>FS02</td>
<td>25,4,27</td>
</tr>
<tr>
<td>FS03</td>
<td>29,10,11</td>
</tr>
<tr>
<td>FS04</td>
<td>21,1,30</td>
</tr>
<tr>
<td>FS05</td>
<td>27,5,22</td>
</tr>
<tr>
<td>FS06</td>
<td>20,0,30</td>
</tr>
</tbody>
</table>

The results show that:

- Air temperatures and CO levels remain well below the tenability limits of 100°C and 2,800 ppm, respectively, for all floor levels. This is applicable to all base and sensitivity cases.
- Air temperatures also remain well below the limiting temperatures of steel and concrete. This is applicable to all base and sensitivity cases.
- Radiant heat levels in the egress paths away from the fire (refer to Graphs in Appendix C) are well below 2.5 kW/m².
- Visibility remains above 10 m in all the base case scenarios. In a number of sensitivity cases it drops below 10 m [shown as (bold) in the table above]. Based on further analysis of the results, the locations where the visibility initially drops below 10m is generally in the areas near the fire or voids where occupants would have evacuated from. When the visibility on the floor decreases below 10 m, occupants are expected to be queuing at exits and hence do not require 10m of visibility.

The results also show that the air temperatures, CO levels and radiant heat levels within the building spaces generally stabilise and remain largely unchanged before the end of the analysis period (refer to graphs in Appendix C). It is therefore expected that they would also
remain largely unchanged should the analysis continue for a longer period of time, or even indefinitely. The following graphs provide a sample of the stabilized ASET results for FS05.

*Figure 14 Stabilised ASET results for FS05 after 1800 s*

Given that the air temperatures, radiant heat levels and CO levels are well below the tenability limits and their values remain unchanged with time, it can be concluded that the building spaces would be tenable indefinitely with respect to these three quantities. Hence, the ASETs for the floor levels may be summarised as shown in the following table.
### Table 5  ASET for Proposed Design (in seconds)

<table>
<thead>
<tr>
<th>Criterion</th>
<th>L0</th>
<th>L1</th>
<th>L2</th>
<th>L3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air temperature</td>
<td>$\infty$</td>
<td>$\infty$</td>
<td>$\infty$</td>
<td>$\infty$</td>
</tr>
<tr>
<td>CO level</td>
<td>$\infty$</td>
<td>$\infty$</td>
<td>$\infty$</td>
<td>$\infty$</td>
</tr>
<tr>
<td>Radiant heat level</td>
<td>$\infty$</td>
<td>$\infty$</td>
<td>$\infty$</td>
<td>$\infty$</td>
</tr>
</tbody>
</table>

It is noted that the results above are compiled from the relevant worst fire scenarios for each floor level including the sensitivity fire scenarios.

### 6.3 RSET Analyses

Evacuation times for the shopping centre are determined by means of computer simulations using the program Pathfinder [15], which is an agent-based egress and human movement simulator that uses steering behaviours to model occupant motion.

#### 6.3.1 Pathfinder model

For the purpose of the evaluation, a 3-D computer model was constructed for the building for the proposed design. The figures below show the model of the building when fully occupied with the assumed population density as follows (based on FCRC population densities):

- Level 0 Mall space – 10 m$^2$/person
- Level 0 Shops - 6 m$^2$/person
- Levels 1 to 3 – 10 m$^2$/person
- Level 3 Cinema Theatres – 960 persons (as advised in brief)

![Pathfinder Model of Proposed Design](image)

#### Figure 15  Pathfinder Model of Proposed Design

### 6.3.2 Assumptions

The following general and conservative assumptions are made in the analysis:

- The shopping centre is fully occupied with the FCRC Project 6 recommended population numbers rather than BCA assumed population, as shown in the following figure.
All the occupants within the centre commence evacuation at the same time. This is the worst case scenario as occupants from each level fill the stairs at the same time.

The stairways and escalators are used for occupant movement between the floor levels.

The occupants within the enclosure at the perimeter of the building on the ground level (Level 0) move directly to the outside using the doorways that lead to the outside.

The occupants on the upper levels also use the stairways at the perimeter to move down the building.

6.3.3 Analysis results

Each scenario was analysed for the period till all occupants have moved out of the building.

The movement times for the occupants to move out of each floor level (into the stairway) or out of the building are summarised in the figure below.

The result shows that the occupants could move out of the entire shopping centre in 900 s.
The RSET value for each floor may be taken as the corresponding movement time in the figure above plus pre-movement time. As recommended in FCRC 6, pre-movement time may be ignored for occupants located in the vicinity of the location of fire.

6.4 ASET vs RSET

Given that the building remains tenable indefinitely with respect to air temperatures and CO level, the ASET is greater than the RSET for all cases examined. Hence:

$$\text{ASET} > \text{RSET}$$

Nevertheless, in order to determine if way finding is an issue visibility in the centre during the fire is further examined.

The following table summarises the time when visibility drops below 10 m. It should be noted that these values are conservative estimates and are based on the first instance where any gas phase device located in the egress paths drops below 10 m. At these times 10 m of visibility is still maintained in areas away from the fire or voids.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Time (s) when visibility first drops below 10 m</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>L0</td>
</tr>
<tr>
<td>FS01</td>
<td>$\infty$</td>
</tr>
<tr>
<td>FS02</td>
<td>$\infty$</td>
</tr>
<tr>
<td>FS03</td>
<td>$\infty$</td>
</tr>
<tr>
<td>FS04</td>
<td>$\infty$</td>
</tr>
<tr>
<td>FS05</td>
<td>$\infty$</td>
</tr>
<tr>
<td>FS06</td>
<td>$\infty$</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Time (s) when visibility first drops below 10 m</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>L0</td>
</tr>
<tr>
<td>FS04-a</td>
<td>$\infty$</td>
</tr>
<tr>
<td>FS04-b</td>
<td>$\infty$</td>
</tr>
<tr>
<td>FS05-a</td>
<td>$\infty$</td>
</tr>
<tr>
<td>FS05-b</td>
<td>371 s</td>
</tr>
</tbody>
</table>

The results show that in all the base cases examined, the occupants would have sufficient time evacuate prior to visibility dropping below 10 m.

In the sensitivity scenarios, further analysis of the visibility slice files show that the visibility levels elsewhere in the building away from the fire and voids are still maintained above 10 m, occupants are provided with sufficient visibility to evacuate the building. Visibility slice files indicating the extent of reduced visibility for FS04-b is shown in Figure 18.
The assessment shows that ASET is greater than RSET for the mall spaces with a significant margin of safety. Sufficient visibility is also maintained in the base case design and sensitivity design to allow occupants to evacuate the building.

It shows that the Proposed Design exhibits a high level of fire safety for the occupants and:

**Objective 1 is achieved ✓**
EVALUATION AGAINST OBJECTIVE 2 – FIRE BRIGADE INTERVENTION

In the previous section, the evaluation focuses on the tenability conditions of the building immediately after the fire starts until the occupants move to a place of safety. The conditions over this period of time may be regarded as “early tenability” of the building. Analysis results for this case study show that this period concerned is no more than 900 s.

The Fire Brigade, however, would arrive relatively later in the event of a fire. Their safety, should they decide to enter the building, is therefore dependent on the tenability conditions of the building at a later stage. This may be regarded as “later tenability”, which generally occurs after the occupants have evacuated the building.

7.1 Tenability Limits

The Australasian Fire Authorities Council Fire (AFAC) has also developed criteria for fire fighters using a similar approach for short exposure periods [16]. The criteria for fire fighters are typically more severe given that they are better equipped with protective gear (see Table below).

Table 8  AFAC Tenability Limits for Fire Fighters

<table>
<thead>
<tr>
<th>Condition</th>
<th>Routine</th>
<th>Hazardous</th>
<th>Extreme</th>
<th>Critical</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max Time</td>
<td>25 minutes</td>
<td>10 minutes</td>
<td>1 minute</td>
<td>&lt; 1 minute</td>
</tr>
<tr>
<td>Max Air Temperature</td>
<td>100°C</td>
<td>120°C</td>
<td>160°C</td>
<td>&gt; 235°C</td>
</tr>
<tr>
<td>Max Radiation</td>
<td>1kW/m²</td>
<td>3kW/m²</td>
<td>4 - 4.5kW/m²</td>
<td>&gt; 10kW/m²</td>
</tr>
</tbody>
</table>

AFAC appears to have set an exceedingly low radiant heat limit of 1.0 kW/m² for a routine fire fighting condition. The limit is lower than the heat flux received from sun bathing in the tropics, which is estimated to be 1.1 kW/m² [19].
7.2 Fire Brigade Intervention

In order to estimate the Fire Brigade Intervention, the AFAC Fire Brigade Intervention Model (FBIM) Charts [16] are used to model their response to a fire in the building.

Some of the main assumptions are as follows:

- A fire occurs in the cinema complex located on Level 3 which is considered to be the worst case scenario as it is the most remote location in the building.
- Automatic alarm detection via smoke detectors with automatic direction connection to fire brigade.
- Brigade turnout time is based on a standard response time of 7.7 minutes.
- 2 x fire trucks and 8 fire fighters attend site.
- Travel distance for search and rescue of Level 3 is 500 m.

The results are contained in Appendix D and are summarised below.

<table>
<thead>
<tr>
<th>Fire Brigade activity</th>
<th>Time from fire start (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arrival on site</td>
<td>682 s</td>
</tr>
<tr>
<td>Apply water to fire</td>
<td>2,715 s</td>
</tr>
<tr>
<td>Complete walk-through &quot;search &amp; rescue&quot; of Level 3</td>
<td>3,381 s</td>
</tr>
</tbody>
</table>

7.3 Brigade tenability

The fire modelling, as discussed in the previous section, shows that, in both the sprinklered and unsprinklered fires, the air temperatures within the building remain less than 100°C indefinitely. The radiation levels in the egress routes are also less than 1.0 kW/m². Based on this routine conditions for fire fighters are expected.

As fire fighters approach a fire (< 10m), temperatures and radiant heat levels will increase to potentially hazardous or extreme conditions, however the trained fire fighters will position themselves in a safe location to fight the fire and are able to move back out of the fire affected area if required.

The centre is provided with a 60 minute FRL throughout as a means of redundancy. The fire modelling shows that temperatures in the centre are well below the limiting temperatures of structural steel and concrete. In addition, occupants in the building would have evacuated and fire fighters can commence applying water to a fire within 60 minutes period.

Under these conditions, the fire brigade will be able to enter the building and fight the fire inside the building using the hydrants inside the building. The fire brigade will be able to conduct search and rescue in the building. Hence:

**Objective 2 is achieved ✔️**
8 EVALUATION AGAINST OBJECTIVE 3 – MINIMISE SMOKE AND FIRE SPREAD

8.1 Limiting Fire Spread

Given that the building is fully sprinkler protected, fire in the building is controlled and confined to the area of fire origin. The sprinklers also prevent it from spreading beyond the area and enclosure of fire origin.

Barriers are also provided within the ceiling space to prevent fire spread within the ceiling space.

8.2 Limiting Smoke Spread

Smoke from a fire may spread throughout the connected spaces in the building. However, as part of the performance based design, its spread is limited and the extent of smoke spread is discussed below.

8.2.1 Limiting spread into retail areas

The individual retail areas, including the major stores, specialty shops and cinemas, are smoke separated from each other by virtue of its wall construction (generally full height walls separating shops). As part of the performance design, they are also smoke separated from the mall area as follows:

- Each major store is smoke separated from the mall by means of a baffle and/or automatic shutters at the mall entry. These shutters descend to a 2m height above the floor upon detection of fire in the major store or near the shutter.
- The cinema complex is smoke separated from the mall by means of baffle and/or automatic shutter at the mall entry which descends to a 2m height above the floor upon detection of a fire in the cinema complex or near the shutter.
- Each specialty shop is smoke separated from the mall by means of its shopfront wall and baffle above its doorway.

With the above provisions in place, smoke spread into the majors and cinema complex would be minimized as the smoke detectors provided in front the shutters would detect smoke and initiate the descent of the shutters. The 2 m height still allows for occupants to pass through the shutter and provides a baffle to minimize smoke spread into the store.

The specialty shops will be provided with a shop front wall and baffle above its doorway to minimise the extent of smoke spread in.

The provision of a natural ventilation smoke management system in the mall space also vents smoke out of the building minimizing the spread of smoke to the stores.

The extent of smoke spread from a fire in the centre is further discussed in the following sections based on a fire occurring in the mall space, specialty shops and majors.
8.2.2 Limiting spread into mall area

As part of the performance design, smoke is prevented from spreading into mall area from the major stores and cinema complex as follow:

- Each major store is equipped with automatic smoke exhaust and smoke separated from the mall as discussed earlier.
- The cinema complex is equipped with automatic smoke venting and smoke separated from the mall as discussed earlier.

The results of fire modelling (Fire Scenarios 3 and 6) show that, in the event of fire occurring in a major store or cinema complex minimal smoke spread into the mall space occurs outside of the major store or cinema.

Figure 20  FS03 Extent of smoke spread out of Level 0 major store fire

Figure 21  FS06 Extent of smoke spread out of cinema

8.2.3 Limiting extent of smoke spread in mall area

As part of the performance design, smoke produced into the mall area, including those from specialty shops, is allowed to spread vertically up the building through floor void and vented out to the roof vents. The strategy is to provide enough roof vents such that smoke spread within the mall in the horizontal direction is limited.
To provide a conservative ASET for each fire scenario, the fire modelling (Fire Scenarios 1, 2, 4 and 5) conducted assumed full height walls around all the stores to confine smoke within the mall space only. This leads to a worst case design in terms of smoke spread throughout the mall areas. Had the stores been open, smoke would spread into the stores and dilute leading to less smoke spread within the mall space.

The results show that in the worst case fire scenarios where the fire is occurring at the lowest floor level, smoke does not spread throughout all the mall spaces of the shopping centre. The extent of smoke spread throughout the mall space is shown in the following figures. It can be reasonably expected that if the smoke is located in the mall space where the shops open into, smoke spread into these shops is also possible.

Figure 22  FS01 Extent of smoke spread out from mall fire

Figure 23  FS02 Extent of smoke spread out from mall fire
In the sensitivity scenarios, smoke spread is still limited. The following figures show the extent of smoke spread in the shopping centre in the sensitivity scenarios.
Figure 26  FS04-a Extent of smoke spread out from specialty store

Figure 27  FS04-b Extent of smoke spread out from specialty store
For the purpose of this assessment the objective is to minimize smoke spread throughout the centre.

The results show that smoke spread from a fire in the proposed design is minimized and:

**Objective 3 is achieved ✅**
9 EVALUATION AGAINST OBJECTIVE 4 – LIMIT IMPACT ON BUSINESS CONTINUITY

9.1 Business disruption

Business disruptions will occur both during a fire and after the event of the fire.
- During the event of fire, the area of fire origin and the area affected by the fire will need to be evacuated. Business will be suspended in these areas during this time. Business loss could occur from smoke and fire damage due to a fire and also loss of business due to the evacuation of the building.
- After the event of fire, business may resume when the shopping centre is determined to be safe to occupy. However, the areas affected by the fire may need to be repaired or cleaned up prior to occupations. Business in these areas will be suspended until the repair and clean up are complete.

The extent of business disruption will depend on:
- Extent of the shopping centre need to be evacuated during the event of the fire
- Extent of repair and clean up of the fire affected areas after the event of the fire

9.2 Limiting impact on business continuity

9.2.1 During the event of fire

The fire modelling results show that the shopping centre overall remains tenable in the event of fire, including the sensitivity case of sprinkler failure. Hence only areas affected by the fire need to be evacuated first. Other areas may progressively be evacuated when required, as directed by the building management through the warden system. This would assist in managing occupant movement in fire affected area and also minimise business disruption to areas not affected by the fire.

Based on the performance design of the centre, evacuation is to be directed by the wardens and the centre may be evacuated as follows:
- Major stores – in the event of a fire occurring in a major store, the store of the fire origin is to be evacuated immediately. The occupants in the major store may move to the mall area, which is designed as a safety place. The adjoining mall and other parts of the centre need not be evacuated unless smoke starts to spread into the mall area. Floor area directly above the major store may also need to be evacuated as instructed by the fire brigade when they attend and assess the fire.
- Cinema complex – in the event of a fire occurring in cinema, the cinema complex is to be evacuated immediately. The occupants in the cinema complex may move to the mall area, which is designed as a safety place. The adjoining mall and other parts of the centre need not be evacuated unless smoke start to spread into the mall area.
- Mall area – the mall area is divided into 3 zones: East, Centre and West. When smoke spreads into the mall, the zone concerned is to be evacuated. Other zones need not evacuate unless smoke starts to spread to the zone.

The above strategy would help the centre management control the evacuation and also limit the impact on business continuity of the areas not affected by the fire.
9.2.2 After the event of fire

After the event of fire, the fire safety systems including the sprinkler systems are to be reinstated. When the centre is determined to be safe to be occupied, businesses in the area not affected by the fire may continue.

Businesses affected by fire and/or smoke will need to be repaired and cleaned prior to re-occupying. The sprinklers and smoke management system provided in the proposed design have been demonstrated to be highly effective in limiting fire spread and also limiting smoke spread throughout the building. These provisions minimise the effects of fire on businesses outside the area of fire origin.

With the strategy outlines impact on business continuity shopping centre is limited and:

Objective 4 is achieved ✓
10 CONCLUSIONS

A performance-based design has been presented for the case study which incorporates 4 storey shopping centre interconnected by floor voids.

As part of the performance-based design, a fire engineering strategy has been developed to encompass all the sub-systems as outlined in the International Fire Engineering Guideline and to achieve the design objectives set out for the case study.

The key design features of the Proposed Design include the use of:

- A sound fire safety management of the building to control fire start and occupant evacuation.
- An effective sprinkler system to control the fire growth in the building.
- A reliable natural smoke venting system at the roof to allow smoke to vent from shopping centre through the interconnecting floor voids. Mall is therefore designed as a safe place.
- Normally used circulation paths, external open stairs and escalators for egress purposes.
- Staged evacuation of the mall to minimise business disruption.
- Shutters to the entries of the majors and cinema complex designed to prevent smoke spread.

The evaluation shows that the Proposed Design achieves each and every fire safety objective set out for the case study.
11 REFERENCES


## APPENDIX A

### SS-A: Fire Initiation and Development and Control

### Design Strategy
- To minimise the number of fire starts.
- To extinguish any fire before it becomes threatening.

### Design Principles
- Specific management plans and procedures are to be put in place by the shopping centre management to control the use and activities within the building.
- Sufficient fire extinguishers are to be provided for occupants to fight small fires within the retail areas.

### Design Details

<table>
<thead>
<tr>
<th>Management plans and procedures</th>
<th>Rationale</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specific management plans and procedures are to be developed by shopping centre management using risk management principles as set out in AS/NZS ISO 31000:2009.</td>
<td>If the initiation of fire within a building could be prevented, all the fire safety objectives would be achieved and there would be no need to invest in expensive fire-safety measures. The tasks outlined in Appendix B were developed to specifically target the major cause of fire starts in shopping centre. This is based on the finding of the study of fire statistics in FCRC 6 [8] that, of all reported fires in shops in the USA: 36% are due to heat from electrical equipment arcing or overloading, 15% are due to fuel fired or powered objects.</td>
</tr>
<tr>
<td>The fire safety management tasks are to include all types of activities including communications, maintenance, auditing and training (see Appendix B). These tasks are aimed at minimising the number of fire starts and extinguish the fire before it becomes threatening.</td>
<td></td>
</tr>
</tbody>
</table>

**Sprinkler system**

The centre is to be sprinkler protected throughout to control the growth of fire in the building (details of the sprinkler system will be further discussed later in the paper). Sprinkler protection is considered a key fire safety system of the performance solution. This is based on the finding of the USA data as reported in FCRC 6 [8] that sprinklers appear to reduce the death rate by about a factor of three.

**Fire extinguishers**

Portable fire extinguishers to AS 2444 are to be provided in:
- each specialty shop
- throughout each major store
- enclosures containing power distribution equipment
- kitchens, dining rooms, food and beverage outlets
- hazardous goods or flammable liquids stores

The extinguishers are to be installed at the readily accessible locations in the retail areas and staff are to be trained in the use of fire extinguishers.

Fire extinguishers are proposed in lieu of fire hose reels. This is based on the study in FCRC 6 [8] that occupants are more likely to use fire extinguisher than fire hose reels.

FCRC 6 [8] also shows that fires attended by the fire brigade in the USA, 39% of fires are either self extinguished (15%), or put out with make-shift aids (7%) or portable extinguishers (17%).
SS-B: Smoke Development and Spread and Control

<table>
<thead>
<tr>
<th>Design Strategy</th>
</tr>
</thead>
<tbody>
<tr>
<td>• To maintain egress paths tenable for occupants to move to place of safety</td>
</tr>
<tr>
<td>• To limit smoke spread to minimise business disruption.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Design Principles</th>
</tr>
</thead>
<tbody>
<tr>
<td>• In the event of a sprinkler controlled fire (C2) anywhere in the centre:</td>
</tr>
<tr>
<td>o all main egress paths in the centre are to remain tenable indefinitely.</td>
</tr>
<tr>
<td>o smoke spread is limited.</td>
</tr>
<tr>
<td>• In the event of sprinkler controlled fire (C2) in a major store or the cinema complex:</td>
</tr>
<tr>
<td>o the smoke produced is to be limited from spreading into the adjoining mall.</td>
</tr>
<tr>
<td>• In the event of an unsprinkler controlled fire (C3) in the centre:</td>
</tr>
<tr>
<td>o all main egress paths are to remain tenable for the expected duration of evacuation using the paths.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Design Details</th>
<th>Rationale</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mall areas</strong></td>
<td>The mall areas are interconnected by floor voids, hence would be difficult to extract smoke from each level of the mall area and prevent the smoke from spreading between the floors through the floor voids. The strategy is to allow smoke spread up the floor voids and allow the smoke to escape the building at the roof level.</td>
</tr>
<tr>
<td>The mall areas are to be served by automatic smoke venting as follows:</td>
<td>For the purpose of this case study, it is also considered desirable and cost-effective to adopt the means of natural venting in lieu of BCA DtS high volume smoke exhaust system. Natural venting is a relatively simple system and can be very reliable.</td>
</tr>
<tr>
<td>• Louvres are to be installed at the roof level at the highest part of the building and evenly distributed along the mall.</td>
<td>The only key factor that may affect the performance of the natural venting is the environment factor such as wind. In order to overcome the effects of wind, the roof is raised or the louvres protected to create a negative region around the lourvre locations. This will further assist in pulling smoke out of the building.</td>
</tr>
<tr>
<td>• The roofline is to be raised, or barriers installed, to protect the louvres against the effects of wind (refer to Figure 10).</td>
<td>The use of natural ventilation also negates the requirement for backup power supply for the mechanical smoke exhaust as the louvres can be configured to be fail safe open. This represents a major cost saving for the building.</td>
</tr>
<tr>
<td>• The louvres throughout the mall space are to be automatically open in full in the event of fire detection anywhere in the building.</td>
<td></td>
</tr>
<tr>
<td>• The floor void openings, which are part of the architectural design, are to be utilised as air paths for smoke in a lower level to travel up to the roof level and be vented out.</td>
<td></td>
</tr>
<tr>
<td>• Entry/exit doors on the Ground Levels are to automatically open to provide make-up air. Open louvres away from the fire also provide make-up air.</td>
<td></td>
</tr>
<tr>
<td><strong>Major stores</strong></td>
<td>Major stores usually have their own system and often operate independently with respect to various systems in the shopping centre. They can be readily designed to have their own smoke exhaust system to</td>
</tr>
<tr>
<td>All major stores having a floor area greater than 2000 m² are to have their own smoke exhaust system with a minimum exhaust rate of 32 m³/s.</td>
<td></td>
</tr>
</tbody>
</table>
A baffle is to be installed at their entrance to the mall to limit smoke spread into the mall area. Alternatively an automatic shutter may be installed to automatically descend to a 2 m height above the floor level to allow occupants to evacuate into the mall. Shutters are to automatically descend to 2m above the floor upon detection of fire in the centre.

<table>
<thead>
<tr>
<th>Specialty shops</th>
<th>Specialty shops do not have their own smoke exhaust system. Hence specialty shops connected to the mall are considered part of the mall with regards to smoke management.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specialty shops</td>
<td>All specialty shops having a floor area less than 2000 m² connected to the mall areas are to be considered parts of the mall for smoke management purposes.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Cinema complex</th>
<th>The cinema complex is considered similar to a major store in that it will have its own system and operate somewhat independent of the shopping centre.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cinema complex</td>
<td>The cinemas are installed with smoke vents at the roof level. Smoke curtains or shutters are to be installed at the mall entrance to the cinema complex. The curtain will descend to 2m above the floor upon detection of fire in the centre.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Stairway Pressurisation</th>
<th>This is based on the design strategy of maintaining the mall area tenable. Given that the stairways are connected to the mall area, they will likewise be tenable without pressurisation. Stairways around the perimeter of the building are proposed to be external and open to the outside.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stairway Pressurisation</td>
<td>Stairway pressurisation is omitted. The omission of pressurisation also represent a major cost saving.</td>
</tr>
</tbody>
</table>

The major stores usually have their entrance connected to the mall area. The mall entrances serve as an egress path for the occupants. To prevent smoke spreading into the mall, baffles or automatic shutter are proposed to be installed at the mall entrance.
### Design Strategy
- To maintain the stability of the building to ensure occupant and fire brigade safety
- To minimise the spread of fire to adjacent buildings
- To minimise the spread of fire within the building to maintain business continuity

### Design Principles
- The building is to be designed against spread of fire from the area or enclosure of fire origin.
- The building is to be designed against collapse of multi-level building structure.

<table>
<thead>
<tr>
<th>Design Details</th>
<th>Rationale</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Fire resistance</strong></td>
<td>The fire resistance of the building elements is to be 60 minutes throughout.</td>
</tr>
<tr>
<td><strong>Fire compartmentation</strong></td>
<td>The centre is designed as a single fire compartment and not separated into fire compartments.</td>
</tr>
<tr>
<td></td>
<td>The atria are not separated by bounding construction.</td>
</tr>
<tr>
<td><strong>Ceiling barriers</strong></td>
<td>The walls bounding the major stores and cinemas theatre are to extend to floor slab or roof above.</td>
</tr>
<tr>
<td></td>
<td>Ceiling barriers are to be installed at the boundary of sprinkler zones or at 50 m internals. Ceiling and insulation are to be non-combustible materials.</td>
</tr>
<tr>
<td></td>
<td>Ceiling space barriers may consist of a continuation of the wall construction below the ceiling and be of similar construction (eg. plasterboard linings on either side of a steel stud).</td>
</tr>
<tr>
<td></td>
<td>Gaps around penetrating services should not exceed 50mm at any location.</td>
</tr>
</tbody>
</table>
## Design Strategy
- To minimise the time for detecting fire and alerting occupants in the building
- To minimise the time to suppressing or controlling fire in the building

## Design Principles
- Sufficient means of detection and warning the occupants are to be provided throughout the building.
- A reliable sprinkler system which is commensurate with the hazard is to be incorporated throughout the centre.

## Design Details

<table>
<thead>
<tr>
<th>Fire detection system</th>
<th>Rationale</th>
</tr>
</thead>
<tbody>
<tr>
<td>Smoke detection is to be installed in the mall and within major stores as specified by the BCA (15m apart and 7.5m from walls) and AS 1668.1 (20m apart and 10m from walls) respectively. Automatic brigade call to be provided on the fire alarm panel.</td>
<td>Smoke detectors are installed to provide an early detection of fire. They are to serve to activate the warning system, particularly to the building management to response to the fire and also to activate the smoke management system.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Occupant warning system</th>
<th>Rationale</th>
</tr>
</thead>
<tbody>
<tr>
<td>A Sound System and Intercom System for Emergency Purposes is to be installed in accordance with AS 1670.4.</td>
<td>FCRC 6 has found that occupant warning alone is unlikely to initiate evacuation. The design strategy is to train staff to act as wardens to assist with building evacuation (see Appendix B).</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Sprinkler system</th>
<th>Rationale</th>
</tr>
</thead>
</table>
| The sprinkler system is to be designed in accordance with the requirements AS 2118. As part of the performance-based design strategy, it is to be further enhanced as follows:  
- Fast response sprinklers with a maximum RTI of $50m^{1/2}s^{1/2}$ are used.  
- The system is connected to two town mains water supply, each capable of satisfying the required system flow demand.  
- A monitored isolation valve is installed at each floor level to enable sprinkler isolation of individual floor level.  
- Each major store is served by a control valve, separate from those of the specialty shops. | The sprinkler system is the key fire safety system which is to be enhanced to ensure its reliability. The sprinklers for each level of the building are to be separately valved to reduce the chance of two adjoining zones, being isolated at the one time. The use of monitored valves will support sound management as notification of isolation is required along with time of re-instatement. If the system is not re-instated within the prescribed time period, the fire brigade will arrive at the building to investigate the situation. Sprinklers associated with major stores are to be separately valved to those associated with the specialty shops and mall. This is to reduce the likelihood of the sprinklers within major stores being frequently isolated when the specialty stores are refurbished and vice versa. |
**Design Strategy**
- To provide means for safe egress of occupants put at risk by a fire.

**Design Principles**
- The centre is to be designed for a population density of at least 10m²/person.
- The mall area is to be designed as a safe place for the occupants to move away from the fire and to provide the primary means of escape.
- All major access paths in the mall are to be utilised as egress paths.
- All enclosures and areas within the centre are to be designed to avoid entrapment and have sufficient egress paths to move to a safe place, open space, or roadway, prior to the achievement of untenable conditions.
- An evacuation plan is to be developed and implemented by the building management.
- Evacuation of the centre is to be controlled by building management through a warden system.

<table>
<thead>
<tr>
<th>Design Details</th>
<th>Rationale</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mall as safe place</strong>&lt;br&gt;The mall is to be designed a safe place for people seeking to move away from the fire and to provide the primary means of escape for occupants.&lt;br&gt;All normal access paths include open stairs and escalators within the mall to other levels are utilised for egress purposes.</td>
<td>The mall area is designed as safe place for evacuation as recommended by FCRC 6.&lt;br&gt;Tenability of the mall is maintained by means of sprinkler protection and smoke venting of the mall (see previously discussed strategy).&lt;br&gt;Studies of occupant behaviour and movement suggest that fire-emergency passageway commonly provided for emergency egress from the mall are unlikely to be used by the occupants (including staff) in the event of a fire. A better and alternative concept is to utilise the normal exit/entrance routes as evacuation paths. Wardens will also be provided to direct occupants to exits.</td>
</tr>
<tr>
<td><strong>Egress to the mall</strong>&lt;br&gt;For each specialty shop having a single exit to the mall, egress doorways are provided for each enclosure such that the travel distance to the mall is not more than 20 m.&lt;br&gt;Where the shops or stores having a frontage of more than 50 m, at least two doorways are provided for the occupants to move into the mall.</td>
<td>The maximum travel distance and exit separation is to ensure occupants have sufficient time to move out of the shops or major stores into the mall area.&lt;br&gt;Provisions of alternative egress routes for enclosure having a large frontage is to avoid the occupants being trapped in the enclosure should one of the egress route become unusable due to fire.</td>
</tr>
<tr>
<td><strong>Egress to the outside</strong>&lt;br&gt;For each specialty shop having a single exit to the mall, egress doorways are provided for the shops and stores on the ground level located at the perimeter of the centres for the occupants to move directly to the outside with a maximum travel distance of 30 m.</td>
<td>The mall is designed as a safe place for the occupants to immediately move to in the event of a fire.&lt;br&gt;The egress doorway at the perimeter of the building on ground level and the stairways at the perimeter of</td>
</tr>
<tr>
<td><strong>Egress stairways</strong></td>
<td>the building are designed for the occupants to move from the mall to the outside.</td>
</tr>
<tr>
<td>----------------------</td>
<td>----------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Egress stairways are provided around the perimeter for the occupants on the upper level to move down the centre and out of the building.</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Egress Sequence</strong></th>
<th>Due to the interconnection of the floor levels within each section, it is necessary to commence evacuation of all affected floor levels/areas at the same time when fire is detected.</th>
</tr>
</thead>
<tbody>
<tr>
<td>In the event of fire detection in a major store or the cinema complex, the occupants in the store or cinema complex are to evacuate into the mall. The mall need not be evacuated unless fire is detected in the mall.</td>
<td></td>
</tr>
<tr>
<td>In the event of fire detection in the mall, the affected zone is to be evacuated first. Adjoining zones will go into alarm as the emergency warning system cascades.</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Exit signs and emergency lighting</strong></th>
<th>Exit signs and emergency lights are to be installed to assist occupants in finding their way to the exits and to the outside.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exit signs and emergency lights are to be installed in accordance with the requirements of BCA</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
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</thead>
<tbody>
<tr>
<td>Exit signs and emergency lights are to be installed in accordance with the requirements of BCA</td>
<td></td>
</tr>
</tbody>
</table>
SS-F: Fire Services Intervention

### Design Strategy
- To provide sufficient notification and means of fire fighting for the fire brigade
- To safeguard fire fighting operation

### Design Principles
- Sufficient means of notification of a fire is to be provided.
- Sufficient fire brigade access to the building and the relevant part of the building is to be provided.
- Sufficient communication within the building is to be provided.
- Sufficient hydrants are to be provided and suitably located to facilitate brigade fire fighting.

### Design Details

<table>
<thead>
<tr>
<th>Design Details</th>
<th>Rationale</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Fire Brigade Notification</strong></td>
<td>The fire detection system is monitored and the Fire Brigade is automatically called upon detection of fire.</td>
</tr>
<tr>
<td>The fire detection system is monitored and the Fire Brigade is automatically called upon detection of fire.</td>
<td>A MIMIC panel is to be provided at each major entrance.</td>
</tr>
<tr>
<td><strong>Fire Brigade Access</strong></td>
<td>It is important that the fire brigade has access to each major entrance of the building.</td>
</tr>
<tr>
<td>Fire brigade access is to be provided to each major entrance and to the exit stairway of the building.</td>
<td>The provision of continuous vehicular access as required by BCA is not critical provided the brigade can be directed to the appropriate entrance.</td>
</tr>
<tr>
<td><strong>Internal hydrants</strong></td>
<td>Given the building is sprinkler protected, the fire brigade will be able to fight the fire within the building.</td>
</tr>
<tr>
<td>Hydrants are to be provided in accordance with AS 2419.</td>
<td></td>
</tr>
</tbody>
</table>
APPENDIX B  FIRE SAFETY MANAGEMENT

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

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

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

Responsibilities of Building Owners and Occupiers

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

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

Fire-safety Management Plan

Having established the objectives of the fire-safety management plan it is necessary to develop the plan. This plan should be developed by reference to AS NZS ISO 31000 since managing fire safety is really managing the risks associated with potential fires. The process that should be used in this regard is illustrated in flowchart shown on the right.

The plan shall be documented and communicated to staff. The successful implementation of the fire-safety management plan requires ongoing communication, consultation and review especially with those who will be involved in implementing the plan.
Fire-safety management tasks
Application of the above process to shopping centre situations has resulted in the identification of many fire-safety management tasks. These are given in the summary table below. These are tasks which are likely to be important but no attempt has been made to rank them in order of priority. It will be noted that each of these tasks can be considered as involving a particular type of action:

<table>
<thead>
<tr>
<th>Types of Actions</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Communication of issues and procedures</td>
</tr>
<tr>
<td>2</td>
<td>Maintenance</td>
</tr>
<tr>
<td>3</td>
<td>Refurbishment</td>
</tr>
<tr>
<td>4</td>
<td>Auditing</td>
</tr>
<tr>
<td>5</td>
<td>Reinforcement</td>
</tr>
<tr>
<td>6</td>
<td>Training</td>
</tr>
</tbody>
</table>

**Table 10  Summary of Management Tasks**

<table>
<thead>
<tr>
<th>MINIMISING FIRE STARTS</th>
<th></th>
</tr>
</thead>
</table>
| Development and communication of rules regarding storage of combustibles | (a) rules need to be developed and documented with respect to:  
  • no storage within SOU ceilings  
  • no storage close to switchboards and other electrical/mechanical equipment  
  • penalties for non-compliance  
(b) rules need to be well communicated with photographs showing acceptable and unacceptable situations. |
| Routine maintenance of equipment | Maintenance of electrical and mechanical equipment aimed at reducing likelihood of overheating or electrical faults and consequent fires. Maintenance actions shall be documented and filed for easy recall. |
| Establish and communicate "hot work" procedures | These procedures must be documented and communicated. All workers undertaking cutting, welding, or other hot work must:  
  • remove or cover combustibles below or adjacent to the hot working area  
  • carry a functional portable extinguisher  
  • be trained in the use of extinguishers  
  • "sign on" before work is started and "sign off" after completion  
  • understand penalties for non compliance |
| Ongoing upgrade of electrical lighting and wiring | Older higher voltage lighting and older wiring may represent significant sources for fire initiation. Modifications shall be documented and filed for easy recall. |
| Routine inspections of storage of combustibles in relation to potential heat sources such as switchboards and mechanical equipment |  |
Storage of goods in close proximity to electrical and mechanical equipment can lead to overheating and fire initiation. These audits shall be documented and filed for easy recall.

Audits of "hot spots" in switchboards and equipment
Can be accomplished using thermal imaging cameras. These audits shall be documented and filed for easy recall.

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

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

**EARLY DETECTION**

Establish and communicate who should be notified in the event of a member of staff observing a fire start or smoke
This will most likely be centre management/security staff. Need to also establish how such notification is to be made.

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

Maintenance of automatic fire detection and alarm equipment
This is concerned with the operability of FIP’s and associated automatic detection systems such as smoke detectors.

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

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

**EARLY SUPPRESSION**

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

Maintenance of portable extinguishers
Training of general and security staff in the use of portable extinguishers
Required

**LATER SUPPRESSION**

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

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

Maintenance of sprinkler and hydrant systems

Establish and communicate policy with respect to storage of combustibles in relation to sprinkler heads
The aim is to:
- limit the shielding due to stored combustibles and non-combustibles in order to maximise sprinkler effectiveness
- explain the consequences of not complying
• establish and communicate penalties for non-compliance

Auditing of combustibles and non-combustibles in relation to sprinkler heads

Aim is to provide a mechanism to measure and reinforce compliance with above policy so as to ensure that sprinklers are not overrun due to late activation or to water not being able to get to fire.

Establish and communicate policy with respect to sprinkler isolation

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

Policing of penalties for non-compliance with procedures

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

**EFFECTIVE EVACUATION**

Development and communication of evacuation plan

Maintenance of smoke control systems, doors to stairways, exit signs and emergency lights

Auditing of combustibles in exit paths

This is concerned with ensuring that:
• no combustibles in exits, corridors or stairs
• exit paths are free of obstacles

Policing of rule for no combustibles in exits

• no storage within exits, corridors or stairs

Practice and training in relation to evacuation plan

It is important that staff have an awareness of their responsibilities and that this is reinforced by training and practice.
Fire Scenario FS01 – C2 fire on Level 0 below atrium void
Fire Scenario FS02 – C2 fire on Level 0 below atrium void
Fire Scenario FS3 – C2 fire on Level 0 in major store
Fire Scenario FS04 – C2 fire on Level 0 in specialty shop
Fire Scenario FS4-a (sensitivity) – Increased C2 fire on Level 0 in specialty shop

- Heat release rate (kW)
- Air temperature (°C)
- CO (ppm)
- Radiation (kW/m²)
- Visibility (m)

Graphs showing data over time for each parameter.
Fire Scenario FS04-b (sensitivity) – C3 fire on Level 0 in specialty shop

- Heat release rate (kW) vs. time (s)
- Air temperature (°C) vs. time (s)
- CO (ppm) vs. time (s)
- Radiation (kW/m²) vs. time (s)
- Visibility (m) vs. time (s)
Fire Scenario FS05 – C2 fire on Level 0 in specialty shop

[Diagram showing a floor plan with a fire incident marked]

[Graphs showing heat release rate, air temperature, CO concentration, radiation, and visibility over time for different locations]
Fire Scenario FS05-a (sensitivity) – Increased C2 fire on Level 0 in specialty shop
Fire Scenario FS05-b (sensitivity) – C3 fire on Level 0 in specialty shop
Fire Scenario FS06 – C2 fire on Level 3 in cinema
APPENDIX D FBIM ANALYSIS

General
The information supplied by the Fire Brigade Intervention Model (FBIM) developed by the Australasian Fire Authorities Council [16] was used to determine quantitatively the time for fire brigade intervention activities. These include the time for fire brigade units to respond to a call and arrive at the site, conduct an initial assessment of the scene and setup water supply.

The following assumptions were made in this analysis:
- Brigade turnout time is based on a standard response time of 7.7 minutes.
- 2 x fire appliances and 8 fire fighters (FF) attend site.

Fire Scenario
A fire occurs in the cinema complex located on Level 3 which is considered to be the worst case scenario as it is the most remote location in the building. The cinema complex is provided with sprinklers and smoke detection. Smoke detectors are assumed to activate 80 s after ignition.

The figure and table below summarize the results of the FBIM for this scenario.
<table>
<thead>
<tr>
<th>Task Name</th>
<th>Activities</th>
<th>Activity Time (s)</th>
<th>Task Time (s)</th>
<th>Elapsed Time (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Alarm activation and verification</strong></td>
<td>• Activation of smoke detector (worst case detector activation time)</td>
<td>80</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Time delay for alarm verification</td>
<td></td>
<td>20</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td><strong>Transmit call to fire station</strong></td>
<td></td>
<td>30</td>
<td>30</td>
</tr>
<tr>
<td></td>
<td>• Relay and dispatch information by phone or radio</td>
<td></td>
<td></td>
<td>130</td>
</tr>
<tr>
<td><strong>Dispatch 2 pumper appliance and 8 fire fighters (FF) to fire scene.</strong></td>
<td>• Time to travel to fire station, dress, assemble, assimilate information and leave station.</td>
<td>90</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Time to reach fire scene (Fire Brigade standard response time of 7.7 minutes)</td>
<td></td>
<td>462</td>
<td>552</td>
</tr>
<tr>
<td><strong>FF 1-6 don BA equipment &amp; obtain tools</strong></td>
<td>• FF to dismount truck and don BA (90th percentile)</td>
<td>133</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Gather hydrant equipment</td>
<td></td>
<td>56</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Gather forced entry tools</td>
<td></td>
<td>25</td>
<td>214</td>
</tr>
<tr>
<td><strong>FF 7-8 set up hydrant connection</strong></td>
<td>• Remove equipment for hydrant (90th percentile)</td>
<td>56</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Prepare and flush hydrant (90th percentile)</td>
<td></td>
<td>59</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Remove, connect and charge hose (Hydrant - Appliance) (90th percentile)</td>
<td></td>
<td>67</td>
<td>281</td>
</tr>
<tr>
<td><strong>FF 1-6 communicate with fire warden</strong></td>
<td>• Hindrance factor = 1.5</td>
<td>42</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• FF approach entrance 25 m away (90th percentile).</td>
<td></td>
<td>90</td>
<td>153</td>
</tr>
<tr>
<td><strong>FF 1 (OIC) &amp; 2 assess Level 2 and Roof Level</strong></td>
<td>• FF 1 (OIC) &amp; 2 to walk 200m to a stair on the perimeter of the building.</td>
<td>333</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• FF 1 (OIC) &amp; 2 to ascend stair to Level 2, approximately 120 steps (90th percentile).</td>
<td></td>
<td>300</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• FF 1 (OIC) &amp; 2 to walk 200m into Level 2 to assess situation. FF1 (OIC) &amp; 2 approach stair to roof.</td>
<td>333</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• FF1 (OIC) &amp; 2 to ascend stair to roof, approximately 80 steps (90th percentile).</td>
<td></td>
<td>200</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• FF 1 (OIC) &amp; 2 to walk 200m into Roof level to assess situation.</td>
<td>333</td>
<td>1499</td>
<td>2548</td>
</tr>
<tr>
<td><strong>FF 3-6 proceed to Level 3</strong></td>
<td>• FF 5 &amp; 6 to walk 200m to a stair on the perimeter of the building.</td>
<td>333</td>
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<td></td>
</tr>
<tr>
<td></td>
<td>• FF 5 &amp; 6 to ascend stair to Level 3, approximately 160 steps (90th percentile).</td>
<td></td>
<td>400</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Connect and charge hoses from hydrant</td>
<td></td>
<td>108</td>
<td>841</td>
</tr>
<tr>
<td><strong>FF 5 &amp; 6 perform reconnaissance of Level 3</strong></td>
<td>• Reconnaissance of Level 3 (500m per FF)</td>
<td>833</td>
<td>833</td>
<td>3381</td>
</tr>
<tr>
<td><strong>FF 3 &amp; 4 attack fire with hose</strong></td>
<td>• FF 3 &amp; 4 to walk 100m in to Level 3 (90th percentile).</td>
<td>167</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• FF 3 &amp; 4 apply water to fire</td>
<td></td>
<td></td>
<td><strong>2715</strong></td>
</tr>
</tbody>
</table>