38

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Fire Safety Design of Mid-rise Timber Buildings

Basis for the 2016 changes to the National Construction Code

Technical Design Guide issued by Forest and Wood Products Australia

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Guide Map

The primary purpose of this Guide is to provide details of the fire engineering analysis that was undertaken to compare the changes relating to mid-rise timber buildings included in the 2016 edition of the National Construction Code (NCC) with Deemed-to-Satisfy building solutions for similar non-combustible building configurations in the 2015 edition.

Supplementary information relevant to the fire safety design of mid-rise timber buildings has been included to assist building designers and building approval authorities determining compliance with the NCC.

For clarity the Guide has been broken up into four parts:

Part A provides background to the development of the NCC Deemed-to-Satisfy Provisions for mid-rise buildings and a brief introduction to the NCC for those unfamiliar with the Australian National Construction Code.

Part B includes general information relevant to the fire safety design of mid-rise timber buildings. It includes information relating to demonstrating compliance with the NCC by means of the performance and Deemed-to-Satisfy pathways and responsibilities of practitioners for the safe design of buildings.

Part C provides a record of the technical justification for the 2016 changes to the NCC relating to mid-rise timber buildings – the primary purpose of this publication.

Part D provides supplementary information relevant to the fire engineering design of mid-rise buildings and the technical justification described in Part C.

Contents

A

Part A - Preliminaries

Section 1 provides a general introduction and the background to the development of the National Construction Code (NCC) provisions for mid-rise timber buildings.

Section 2, National Construction Code Basics, provides a brief introduction to some key areas relating to timber for those unfamiliar with the Australian National Construction Code.

1 Introduction

The 2016 edition of the National Construction Code NCC[1] includes, for the first time in Australia, Deemed-to-Satisfy (DTS) design solutions for mid-rise timber buildings. These DTS solutions in the 2016 edition apply to mid-rise Class 2, 3 and 5 (residential and office) buildings, and introduce the concepts of fire-protected timber and the use of cavity barriers to the NCC.

There will be applications where it is desired to vary the DTS requirements by developing a performance solution for different building configurations. For example, a design for a high rise building will need to consider, among other things, increased evacuation times, increased time before search and rescue and fire-fighting commence, and the difficulty of external fire-fighting and rescue from the higher levels.

This Guide provides details of the underlying principles and the fire engineering analysis undertaken to support the 2016 changes to assist those who are designing or determining compliance of performance solutions for timber buildings.

1.1 Scope

This Guide will:

- describe the DTS solutions in the NCC 2016 for mid-rise timber buildings and explain the underlying fire safety principles
- provide details of the fire engineering analysis undertaken to compare the mid-rise timber building solution with non-timber DTS solutions
- present useful data and analysis methods relevant to the fire safety design of timber buildings.

1.2 Definition of Mid-rise Timber Buildings

Mid-rise timber buildings are typically 3 to 8 storeys high

Low-rise timber buildings
are buildings of

• Class 1 construction (1 or 2 storey) or

• Class 2 and 3 buildings up to 3 storeys; 4 storeys if the ground level is a concrete or masonry garage.

Mid-rise timber buildings
have an effective height of not more than 25m

Mid-rise timber buildings are typically 4 to 8 storeys high (the maximum number of storeys depends on the floor to floor height)

High-rise timber buildings
have an effective height greater than 25m.

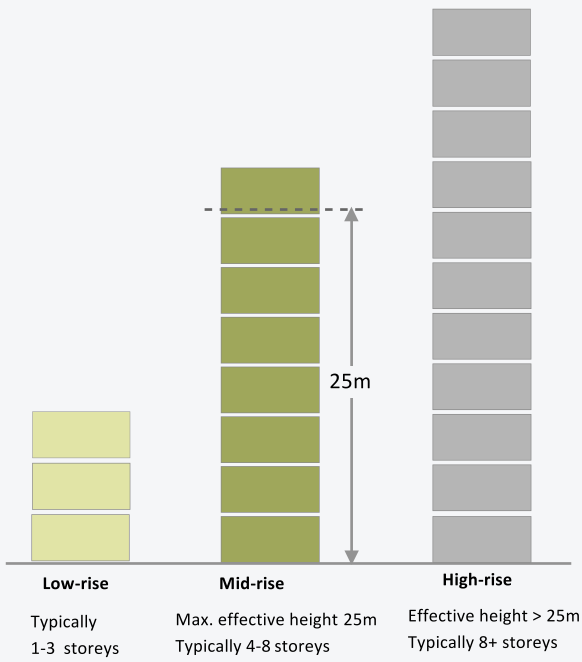


Figure 1.1: Comparison of low-rise, mid-rise and high-rise buildings.

Effective height is defined in the NCC and means the vertical distance between the floor of the lowest storey included in the calculation of rise in storeys and the floor of the topmost storey (excluding the topmost storey if it contains only heating, ventilating, lift or other equipment, water tanks or similar service units).

1.3 Fire-safe Timber Construction

Traditional timber construction, in common with most other forms of construction, has advantages and disadvantages with respect to fire safety. By developing a fire safety design that takes account of these advantages but mitigates the disadvantages, mid-rise timber buildings can be designed to achieve equivalent or better levels of fire safety than other forms of construction such as the Deemed-to-Satisfy solutions prescribed in the National Construction Code 2015[2].

Some of the most relevant fire-related considerations for timber construction are summarised below, together with potential mitigation methods. Appendix A includes information of the response of timber buildings to fires, providing an introduction to readers unfamiliar with the fire safety design of timber buildings as well as supplementary reference data.

1.3.1 Combustibility

Timber is combustible and this has been the reason for placing substantial restrictions on timber mid-rise and high-rise structures within the National Construction Code (formerly the Building Code of Australia) since its initial release in 1988 and general adoption in the early 1990s. Potential issues raised during the consultation process included:

- If timber members are exposed to fire, the timber members may increase the effective fire load within an enclosure, potentially increasing the fire duration/severity of a fully developed fire. The NCC does not specifically limit the fire load that can be introduced into enclosures (other than requiring certain elements to be non-combustible).
- Timber elements/structures may continue to degrade after exposure to fire conditions. Other materials commonly used for structural elements/structures, including masonry and reinforced concrete structures, also degrade after exposure to fire.

These and other issues are discussed in more detail in the body of the Guide and were addressed primarily by specification of automatic fire sprinklers and fire-protective coverings to the timber elements for the prescribed mid-rise timber building solution in NCC 2016. The application of fire-protective coverings is sometimes referred to as encapsulation.

1.3.2 Fire Spread through Voids and Cavities

The potential for fire and smoke spread through buildings via cavities and voids exists with most types of framed construction, unless measures are taken to address the risk. Fire spread can be accelerated if combustible materials are contained within the voids.

The main mitigation measures to address this risk for the prescribed mid-rise timber building solution in NCC 2016 are:

- automatic fire sprinklers
- fire-protective coverings (to prevent fires entering the void)
- specification of non-combustible insulation
- specification of cavity barriers (to prevent uncontrolled fire spread through cavities if a fire enters or starts within a cavity)
- no unfilled voids or cavities permitted if the massive timber provision is applied (see below).

1.3.3 Inherent Fire Resistance of Timber Members

Most structural members require additional fire protection to be applied to provide an adequate level of fire resistance. For example, structural steel normally requires the application of fire protective boards or coatings and reinforced concrete relies on the concrete cover to protect steel reinforcing bars.

Timber having a large cross-section can achieve fire resistance levels (FRLs) in excess of 60/-/-, because when timber is exposed to fire it forms a protective char layer shielding the inner core of the timber as shown in Figure 1.2

Although national some NCC provisions vary by State. It is vital to know the applicable provisions

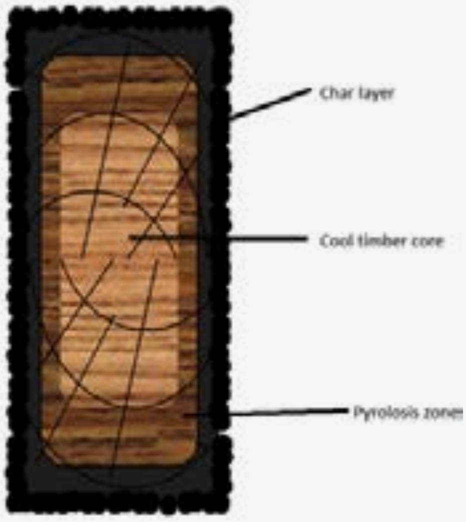


Figure 1.2: Timber member exposed to fully developed fire.

This effect is less pronounced for smaller members and, for engineered products such as lightweight trusses and I-section timber beams, the performance may be dominated by connections or the performance of steel components.

This is recognised in the NCC DTS requirements for mid-rise timber buildings by allowing a 'relaxation' in the performance of the fire-protective coverings for massive timber (without voids and cavities).

In addition, the NCC requires the FRL of a fire-protected timber member to be derived from full-scale tests, rather than solely rely on char calculations based on AS 1720.4, to enable the performance of the adhesives and connections used for engineered products to be verified.

1.3.4 Holistic Fire Safety Approach

A robust fire safety strategy for a building can be achieved by specifying a combination of measures to achieve the objectives that are not overly reliant on any one component.

The prescribed mid-rise timber building solution in NCC 2016 requires the provision of an automatic fire sprinkler system, greatly reducing the frequency of severe fires and hence improving the occupant survivability within the fire compartment of fire origin as well as other occupants within the building.

The combination of automatic fire sprinklers with the above mitigation methods and other requirements within the NCC were shown to provide a significant improvement in life safety for occupants of timber mid-rise buildings compared to equivalent mid-rise buildings of non-combustible construction meeting the Deemed-to-Satisfy requirements of the NCC 2015.

1.3.5 Stakeholder Issues

During the development of the DTS solutions for mid-rise timber buildings, the input of key stakeholders was sought to identify important issues. The main issues are summarised in Appendix B together with an explanation of how the issues were resolved.

2

National Construction Code Basics

The National Construction Code (NCC) is the regulatory framework for determining minimum construction requirements for all types of buildings in Australia.

While most readers will have as a minimum a basic understanding of the NCC, a brief introduction to some key areas is included in this section for those less familiar with the Australian system.

2.1 Building Classes

Refer to NCC Vol One A3.2 for details of all classes of building

The NCC contains mandatory Performance Requirements which apply to 10 primary classes of building. The classes are determined according to the purpose for which the building will be used. The classes considered in the fire engineering analysis described in this Guide were:

- **Class 2** – a building containing two or more sole-occupancy units, each being a separate dwelling, e.g. apartment buildings
- **Class 3** – a residential building which is a common place of long-term or transient living for a number of unrelated persons, including:
  - a boarding-house, guest house, hostel, lodging-house or backpackers accommodation
  - a residential part of a hotel, motel, school, detention centre or health-care building (where accommodating members of staff)
  - accommodation for the aged, children or people with disabilities
- **Class 5** – an office building used for professional or commercial purposes, excluding buildings of Class 6, 7, 8 or 9.

Other major classes defined in the NCC are:

- **Class 1a** – a single dwelling
- **Class 1b** – a boarding house, guest house, hostel or the like with a total area of all floors not exceeding 300 m2 in which not more than 12 persons would ordinarily be resident, which is not located above or below another dwelling or another class of building other than a private garage
- **Class 6** – a shop or other building for the sale of goods by retail or the supply of services direct to the public
- **Class 7a** – a car park
- **Class 7b** – a building used for storage, or display of goods or produce for sale by wholesale.
- **Class 8** – a laboratory, or a building in which a handicraft or process for the production, assembling, altering, repairing, packing, finishing, or cleaning of goods or produce is carried on for trade, sale, or gain.
- **Class 9a** – a health-care building, including those parts of the building set aside as a laboratory
- **Class 9b** – an assembly building, including a trade workshop, laboratory or the like in a primary or secondary school, but excluding any other parts of the building that are of another class
- **Class 9c** – an aged care building
- **Class 10** – a non-habitable building or structure.

Refer to NCC Volume One C1.2

Refer to NCC Volume One C1.1

Refer to NCC Volume One C2.2 for additional area limitations

2.2 Type of Construction

The building class in conjunction with the building height expressed in terms of the rise in storeys is used to determine the type of construction required.

The rise in storeys is the sum of the greatest number of storeys at any part of the external walls of the building and any storeys within the roof space:

- above the finished ground next to that part; or
- if part of the external wall is on the boundary of the allotment, above the natural ground level at the relevant part of the boundary.

Type A construction is the most fire-resisting form of construction and the NCC DTS solutions have in the past imposed severe limitations on the use of timber through the prescription of masonry and concrete construction and non-combustibility for elements required to achieve a prescribed Fire Resistance Level (FRL).

Type B construction does not require FRLs to be as high as those relating to Type A construction, but similar constraints to the use of timber are applied.

Type C construction is applicable to most low-rise buildings. It is the least fire-resisting form of construction and places few fire-related restrictions on the use of structural timber members.

The required Types of construction specified by the NCC are shown in Table 2.1.

Table 2.1: Types of Construction Required by NCC Volume One.

Rise in storeys or effective height	Multi-residential		Office	Retail	Car park/ Storage	Factory/ Laboratory	Hospitals /Public assembly
	Class 2	Class 3	Class 5	Class 6	Class 7	Class 8	Class 9
4 or more	**A**	**A**	**A**	**A**	**A**	**A**	**A**
3	**A**	**A**	**B**	**B**	**B**	**B**	**A**
2	**B**	**B**	**C**	**C**	**C**	**C**	**B**
1	**C**	**C**	**C**	**C**	**C**	**C**	**C**

Note: Clause 2.2 of the NCC also applies area and volume limits on fire compartments based on the Type of Construction

2.3 NCC Compliance Pathways

To comply with the NCC, it must be demonstrated that the relevant performance requirements have been satisfied using the assessment methods specified in the NCC. There are two pathways that can be followed (or a combination of the two):

- For a Deemed-to-Satisfy solution, it is necessary to provide evidence of suitability to show that the prescriptive Provisions within the NCC have been met.
- For a performance solution (previously referred to as an alternative solution), specific building solutions are developed for a building which may vary from the Deemed-to-Satisfy Provisions.

Among other things, this Guide provides details of the fire engineering analysis that was undertaken to establish the Deemed-to-Satisfy solutions for mid-rise Class 2, 3 or 5 timber buildings included in the 2016 edition of the NCC. An objective of this Guide is to inform designers and approval authorities of the underlying principles on which the mid-rise timber Provisions in the NCC are based.

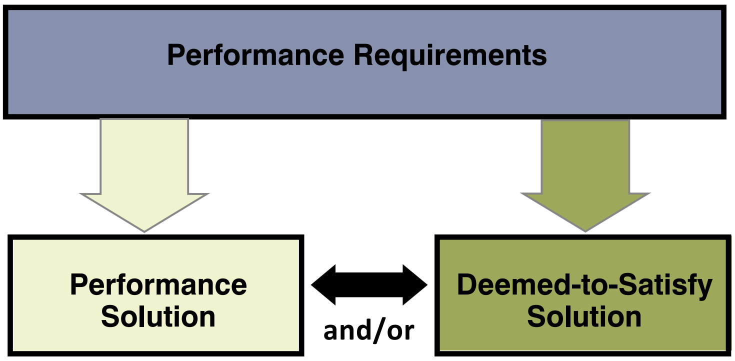


Figure 2.1: Pathways for demonstrating compliance with NCC performance requirements.

2.4 Selection of Compliance Pathways for Timber Buildings

2.4.1 Design Options for Building Classes of Various Heights

In the context of this Guide, timber buildings are defined as buildings where the loadbearing (structural) elements are predominantly timber. It should be noted that there are still opportunities to use timber for some structural and non-structural applications in buildings using other materials for the primary structure of a building.

Table 2.2 summarises options for complying with the NCC performance requirements for Class 2 to 9 buildings with further details provided below. Deemed-to-Satisfy solutions are available for the building configurations shaded in green. All building situations highlighted in blue should be assessed as Performance Solutions using a methodology compatible with that used for justifying the DTS solutions and described in detail in Parts 3 and 4 of this Guide; unless the entire fire safety strategy for the building is derived from first principles.

Table 2.2 Design options for timber buildings.

Rise in storeys or effective height	**Multi-residential**		**Office**	**Retail**	**Car park/ Storage**	**Factory / Laboratory**	**Hospitals / Public assembly**
	Class 2	Class 3	Class 5	Class 6	Class 7	Class 8	Class 9
Effective height greater than 25m	High	High	High	High	High	High	High
Approx. 8	Mid	Mid	Mid	Mid	Mid	Mid	Mid
7	Mid	Mid	Mid	Mid	Mid	Mid	Mid
6	Mid	Mid	Mid	Mid	Mid	Mid	Mid
5	Mid	Mid	Mid	Mid	Mid	Mid	Mid
4	Mid[1]	Mid[1]	Mid	Mid	Mid	Mid	Mid
3	Low[1]	Low[1]	Mid	Mid	Mid	Mid	Mid
2	Low[1]	Low[1]	Low	Low	Low	Low	Mid
1	Low	Low	Low	Low	Low	Low	Low

Note 1: See WoodSolutions Technical Design Guide #2: Timber-framed Construction for Multi-residential Buildings Class 2 & 3 to check if low-rise timber concessions apply.

Low	DTS Solution DG#2 or 3	Mid	DTS Solution –DG#37
Mid	Performance Solution – DG#38	High	Performance Solution

2.4.2 Low-rise Timber Buildings

There are relatively few fire-related restrictions on the use of structural timber members in Buildings of Type C construction irrespective of the Class of Building under the Deemed-to-Satisfy solution pathway and for domestic housing.

The NCC Volume One Deemed-to-Satisfy solution pathway also includes concessions that facilitate the use of timber-framed construction for Class 2 and 3 buildings up to a rise in storeys of 3 and in limited cases up to 4 storeys.

Guidance in relation to construction of these low rise options and Class 1a buildings is provided in the following WoodSolutions Technical Design Guides:

Refer to NCC Spec C1.1 Clauses 3.10 and 4.3 and WoodSolutions Design Guides #1, #2 and #3

#1 Timber-framed Construction for Townhouse Buildings Class 1a – information about complying with the fire safety and sound insulation performance requirements in the NCC for Class 1a attached buildings.

#2 Timber-framed Construction for Multi-residential Buildings Class 2 and 3 – provides information about complying with the fire and sound performance requirements in the NCC for Class 2, 3 low-rise buildings.

#3 Timber-framed Construction for Commercial Buildings Class 5, 6, 9a & 9b – provides information about complying with the fire performance requirements in the NCC for Class 5, 6, 9a and 9b buildings.

These buildings would normally be designed following the Deemed-to-Satisfy solution pathway with performance solutions being used to address minor variations and/or unusual design circumstances.

2.4.3 Mid-rise Timber Buildings

Mid-rise buildings are of Type A or B construction up to an effective height of 25m. The use of timber structural members under the NCC Deemed-to-Satisfy pathway is restricted for mid-rise buildings unless the option to use fire-protected timber in conjunction with automatic fire sprinklers is adopted: as introduced in the 2016 revision of the NCC for Class 2, 3 and 5 buildings. This Guide addresses buildings applying these design principles.

Guidance in relation to construction of these mid-rise options in accordance with the NCC Deemed-to-Satisfy provisions is provided in WoodSolutions Technical Design Guide #37: *Mid-rise Timber Buildings.*

For Class 6 to 9 buildings it will still be necessary to follow the performance solution pathway. Details of the technical derivation of the mid-rise fire-protected timber solution are provided in this Guide: which may assist with the development of a performance solution. Appendix C provides a summary of the Deemed-to-Satisfy clauses in the 2015 edition that were identified as restricting the use of timber and Appendix D identifies the performance requirements that relate to the identified Deemed-to-Satisfy clauses.

Check with the regulatory authority that the building's effective height is not more than 25m if applying the mid-rise fire protected timber solution

The NCC defines effective height as: "the vertical distance between the floor of the lowest storey included in the calculation of rise in storeys and the floor of the topmost storey (excluding the topmost storey if it contains only heating, ventilating, lift or other equipment, water tanks or similar service units)".

Interpretations of the definition of effective height can vary and if there is any doubt as to whether a building's effective height does not exceed 25 m it is recommended that the interpretation is checked with the relevant authorities.

2.4.4 High-rise Buildings

All high-rise timber buildings will need to follow the performance solution pathway.

2.4.5 Mixed Class Buildings

The NCC Deemed-to-Satisfy solution for Class 2, 3 and 5 mid-rise buildings using fire-protected timber in conjunction with automatic fire sprinklers can also be applied to the Class 2, 3 and 5 parts of mixed-class buildings, provided the different classes are adequately fire separated and the entire building is protected by an automatic fire sprinkler system complying with NCC Volume One Specification E1.5.

This provides added flexibility for the design of new buildings and facilitates the recycling of existing buildings without necessarily relying on performance solutions. For example, fire-protected timber apartments (Class 2) could be constructed above existing concrete-framed retail/car park levels minimising the increase in foundation loads, as shown in Figure 2.1.

Fire-protected timber can be used in conjunction with other forms of construction in mixed class buildings

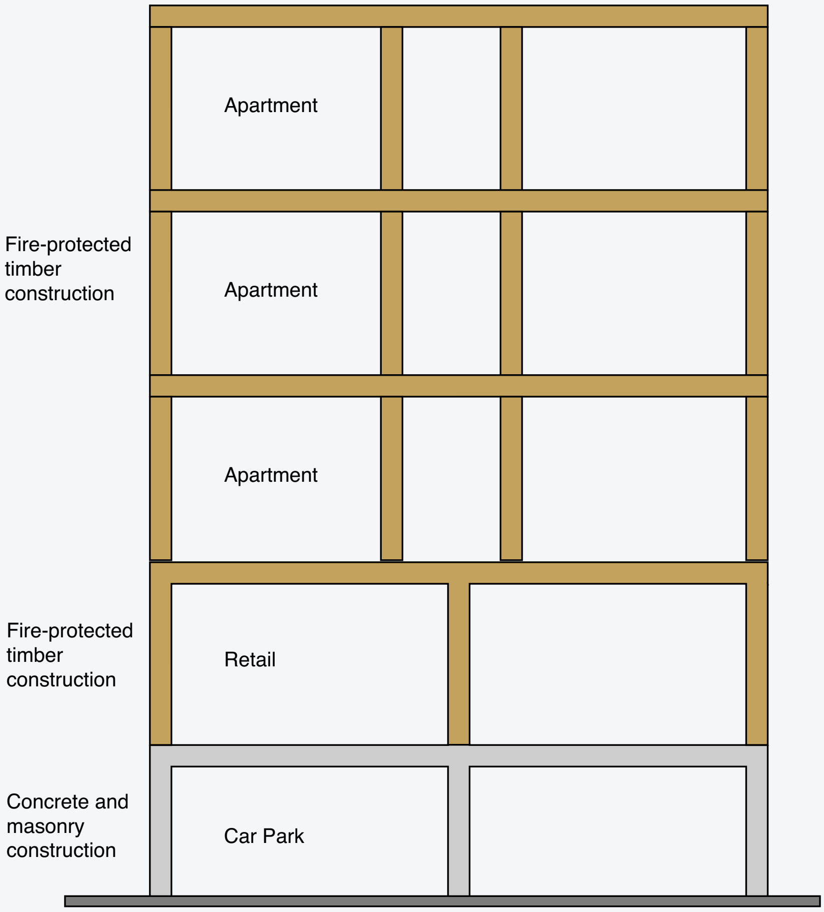


Figure 2.1: Mixed class and mixed forms of construction.

2.5 Resources for Performance Solution Options

In addition to this Guide, the following WoodSolutions Technical Design Guides may assist designers and authorities considering timber performance solutions:

#16 Massive Timber Construction Systems: Cross-laminated Timber (CLT) – introduces the use of CLT in construction, outlining the history, environmental performance and mechanical properties. Also provides an overview of CLT building systems as well as fire, acoustic, seismic and thermal performance.

#17 Alternative Solution Fire Compliance, Timber Structures – provides information about using alternative solutions to allow the use of timber in structural applications not covered by the Deemed-to-Satisfy Provisions of the NCC. It includes a case study of a five storey residential apartment (Class 2) building.

#18 Alternative Solution Fire Compliance, Façades – provides information about using timber façades not covered by the Deem-to-Satisfy Provisions of the NCC. It includes a case study on the use of combustible façades.

#19 Alternative Solution Fire Compliance, Internal Linings – provides information about using timber linings not covered by the Deemed-to-Satisfy Provisions of the NCC. It includes a case study on the use timber linings in a school building corridor.

2.6 Evidence of Suitability

Evidence of suitability for fire resistance and resistance to the incipient spread of fire should be a report from a NATA registered laboratory as prescribed in the NCC

The NCC requires every part of a building to be constructed in appropriate manner to achieve the requirements, using materials and construction methods that are fit for their intended purpose, including the allowance of safe access for maintenance.

The NCC Volume One specifies requirements for Evidence of Suitability in Clause A2.2 but there are the following additional specific requirements that apply to certain aspects of fire safety under NCC Deemed-to-Satisfy requirements:

- NCC Clause A2.3 – Fire-resistance of building elements
- NCC Clause A2.4 – Fire hazard properties
- NCC Clause A2.5 – Resistance to incipient spread of fire.

In most instances, the Evidence of Suitability for the fire resistance or resistance to the incipient spread of fire of an element of construction will be a report from a NATA registered test laboratory presenting the information required by the NCC.

If a performance solution is proposed, a fire safety engineering report should be prepared by a Registered Fire Engineer (note registration requirements vary between the States and Territories). The report should be prepared in accordance with the International Fire Engineering Guidelines and submitted to the relevant regulatory authorities. In many States and Territories additional qualifications/ registration is required for Building Surveyors and Certifiers assessing performance solutions.

B

Part B - Fire Safety Design

Part B of the Guide addresses the fire safety design of mid-rise timber buildings.

Section 3 provides an overview of the responsibilities of designers, builders and other practitioners for the safe design throughout a building's life cycle with an emphasis on fire.

Section 4 outlines the NCC Deemed-to-Satisfy Provisions for mid-rise timber buildings and provides some design options for consideration.

Section 5 highlights commonly raised options for performance solutions under the NCC and some of the key issues for consideration when determining compliance with the NCC.

3 Safe Design

3.1 Building Life Cycle

A typical building life cycle is shown in Figure 3.1.

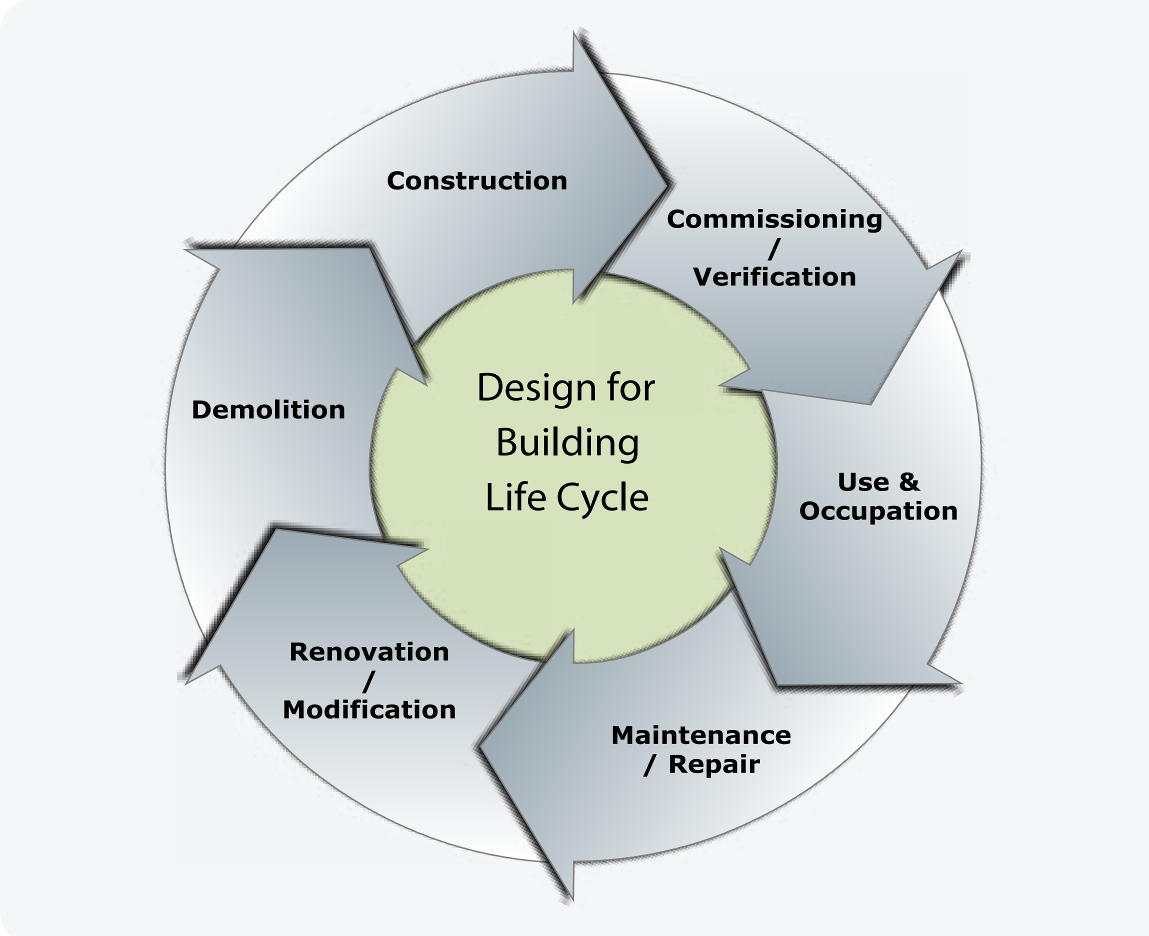


Figure 3.1: Typical building life cycle.

It is important that the impacts of design decisions on all phases of the building's life cycle are considered.

For example, the NCC Deemed-to-Satisfy Provisions may require a particular fire safety feature to be incorporated into a building but, during the design process, it is necessary to determine:

- how the provision can be installed/constructed safely to achieve its required performance
- how the feature will be commissioned and its performance verified
- that the feature will not present a hazard during occupation of a building
- how the feature can be maintained and repaired safely
- measures to be taken to ensure the feature does not present a hazard during renovation/ modification or demolition and to ensure that the performance of the feature is not compromised during the renovation/modification process.

Many of these matters lie outside the scope of the NCC but they are addressed through State and Territory Building Acts and Regulations and Workplace Health and Safety Legislation.

3.2 Responsibilities for Safe Design

For further details on how to address WHS requirements refer to Code of Practice; Safe Design and Structures: published by Safe Work Australia

While this Guide focuses on the 2016 changes to the NCC relating to Deemed-to-Satisfy solutions for mid-rise timber buildings, it should be noted that the NCC provides a uniform set of technical provisions for the design and construction of buildings and other structures throughout Australia. The NCC does not regulate matters such as the roles and responsibilities of building practitioners and maintenance of fire safety measures that fall under the jurisdiction of the States and Territories.

State and Territory Building legislation is not consistent in relation to these matters. There are significant variations with respect to:

- registration of practitioners
- mandatory requirements for inspections during construction
- requirements for maintenance of fire safety measures.

In addition to the relevant Building Regulations, Workplace Health and Safety (WHS) Legislation is also applicable, which requires safe design principles to be applied. A Code of Practice on the safe design of structures has been published by Safe Work Australia[3], which provides guidance to persons conducting a business or undertaking who design structures that will be used, or could reasonably be expected to be used, as a workplace. It is prudent to apply these requirements generally to Class 2 buildings as well as Class 3 and 5 buildings, since they represent a workplace for people undertaking building work, maintenance, inspections and the like.

The Code defines Safe Design as: "the integration of control measures early in the design process to eliminate or, if this is not reasonable practicable, minimise risks to health and safety throughout the life of the structure being designed".

It indicates that Safe Design begins at the start of the design process when making decisions about:

- the design and its intended purpose
- materials to be used
- possible methods of construction, maintenance, operation, demolition or dismantling and disposal
- the legislation, codes of practice and standards that need to be considered and complied with.

The Code also provides clear guidance on who has health and safety duties in relation to the design of structures and lists the following practitioners:

- architects, building designers, engineers, building surveyors, interior designers, landscape architects, town planners and all other design practitioners contributing to, or having overall responsibility for, any part of the design
- building service designers, engineering firms or others designing services that are part of the structure such as ventilation, electrical systems and permanent fire extinguisher installations
- contractors carrying out design work as part of their contribution to a project (for example, an engineering contractor providing design, procurement and construction management services)
- temporary works engineers, including those designing formwork, falsework, scaffolding and sheet piling
- persons who specify how structural alteration, demolition or dismantling work is to be carried out.

In addition, WHS legislation places the primary responsibility for safety during the construction phase on the builder.

From the above, it is clear that the design team in conjunction with the owner/operator and builder have a responsibility to document designs, and specify and implement procedures that will minimise risks to health and safety throughout the life of the structure being designed.

WoodSolutions Technical Design Guide # 20: Fire Precautions During Construction of Large Buildings provides further guidance

WoodSolutions Technical Design Guide #37: Mid-rise Timber Buildings provides typical details that can assist in the application of Safe Design principles

Refer to NCC Volume One Cl E1.9 for NCC precautions during construction

3.3 Applying Safe Design Principles

A key element of Safe Design is consultation to identify risks and practical mitigation measures and to assign responsibilities to individuals/organisations for ensuring the mitigation measures are satisfactorily implemented.

This approach should be undertaken whichever NCC compliance pathway is adopted and applies to all forms of construction.

Some matters specific to fire safety are summarised below, but this list is not extensive:

- The NCC and associated referenced documents represent nationally recognised standards for fire safety for new building works.
- The NCC's treatment of fire precautions during construction is limited and focuses on manual fire-fighting, egress provisions and fire brigade fire-fighting facilities. Additional precautions are required to address WHS requirements such as fire prevention and security. See Section 3.4 and WoodSolutions Technical Design Guide #20: Fire Precautions during Construction of Large Buildings for further information.
- Minimise service penetrations through fire-resistant construction. Further information providing design options is provided in Section 4.9 and WoodSolutions Technical Design Guide #37: *Mid-rise Timber Buildings.*
- Group service penetrations through fire-resisting walls with safe access for installation, inspection and maintenance.
- Develop a detailed design of fire safety measures to optimise reliability and facilitate safe installation, maintenance and inspection where practicable. Special attention should be given to protection of service penetrations and cavity barriers.
- Document procedures and allocate responsibilities for determining Evidence of Suitability for fire safety measures.
- Document procedures and allocate responsibilities for the verification and commissioning of all fire safety installations.
- Provide specifications and drawings of all fire safety measures within the building, Evidence of Suitability, commissioning results and requirements for maintenance and inspection to the owner as part of the fire safety manual. (Note: Some State and Territory legislation contains minimum requirements for inspection of fire safety measures.)
- Include information on how to avoid compromising fire safety through the life of a building (e.g. preventing disconnection of smoke detectors or damage to fire-resisting construction) in the fire safety manual.

3.4 Fire Precautions during Construction

Fires may occur on building construction sites due to the nature of the works.

Typical causes include:

- hot works (cutting and welding)
- heating equipment
- smoking materials
- other accidental fires
- arson.

Mid-rise timber buildings complying with the NCC 2016 edition Deemed-to-Satisfy Provisions offer a safe and economical building option. The addition of the fire-protective coverings plays an important role in providing this fire safety and, due to the construction sequencing, there may be a period where the timber is not fully protected and/or automatic fire sprinkler protection is not fully operational. During this period, timber buildings are at their highest risk from construction fires.

The builder and design team need to consider fire precautions during construction. The scope of the NCC is limited to specifying minimum requirements for fire hydrants, hose reels and extinguishers and egress provisions (NCC Clause E1.9).

Consider fire safety during construction throughout the design process

As identified above, it is necessary to address workplace health and safety issues and a broad holistic approach needs to be adopted that considers the building layout and site layout throughout the construction process to minimise the fire risk at a time when the building could be at its most vulnerable.

Typical matters that should be considered include:

- progressive installation of services
- progressive installation of fire-protective grade lining of timber members and compartmentation of the building
- prefabrication and delivery to site with full or partial fire-protective grade lining of timber building elements
- access for fire fighters and egress provisions for staff and visitors on the building site
- selection of materials and work methods that minimise the need for hot works
- security provisions (to address arson)
- access for fire fighters and egress provisions for staff and visitors on the building site
- safe access for maintenance of equipment and minimising the down time of fire safety equipment during maintenance
- detailing service penetration and construction interfaces to minimise the risk of cavity fires during installation.

WoodSolutions Technical Design Guide #20: *Fire Precautions During Construction of Large Buildings* provides additional information that can be applied to the design and planning stages as well as the actual construction phase.

WoodSolutions Technical Design Guide #37: *Mid-rise Timber Buildings* provides additional information relating to good practice design of service penetration systems and other relevant features of mid-rise buildings

4

NCC Deemed-to-Satisfy Solutions

4.1 Overview of the Deemed-to-satisfy Solutions for Mid-rise Timber Buildings

The NCC 2016 introduced Deemed-to-Satisfy Provisions for the construction of mid-rise timber residential and office buildings. An overview of these changes is shown in Figure 4.1.

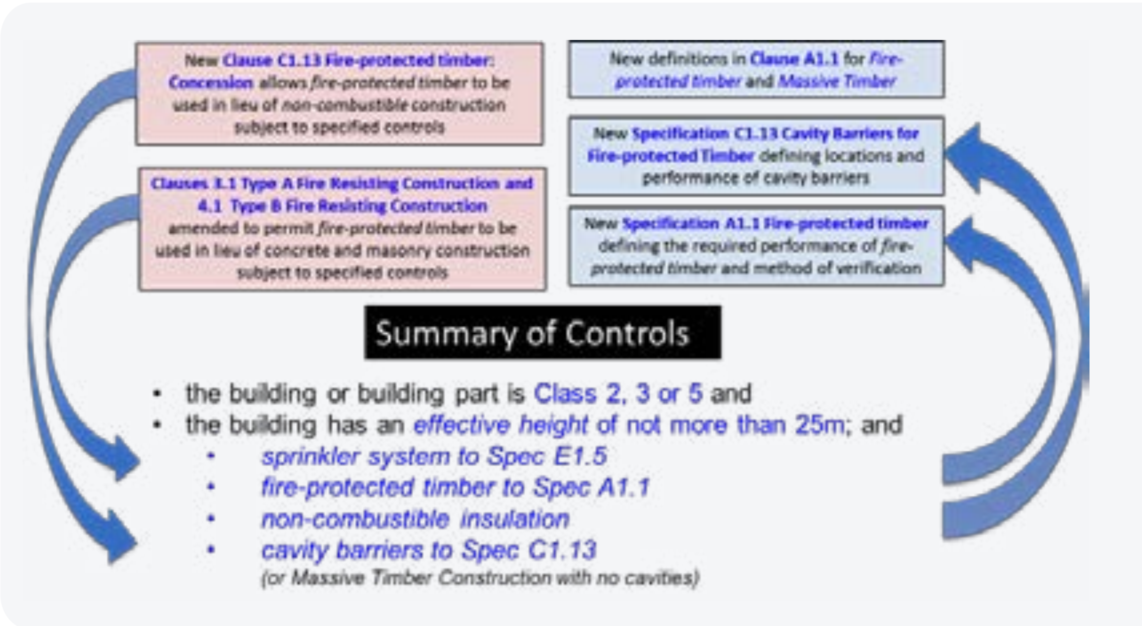


Figure 4.1: Introduction of mid-rise timber provisions to the NCC 2016.

The main features of the mid-rise timber building Deemed-to-Satisfy solutions are:

- The building or building part is of Class 2, 3 or 5.
- Fire-protected timber complying with Specification A1.1 of the NCC is used for loadbearing internal walls, loadbearing fire walls and for elements of construction required to be non-combustible.
- The building has an effective height of not more than 25 m.
- The building has a sprinkler system complying with Specification E1.5 of the NCC throughout.
- Any insulation installed in the cavity of the timber building element required to have an FRL is non-combustible.
- Cavity barriers are provided in accordance with Specification C1.13. of the NCC.

The key objectives of some of the above fire safety precautions that have been adopted to provide a robust building solution are:

Automatic sprinkler suppression system
Objective: To suppress a fire before the structure is threatened and greatly reduce the risk to people and property.

Fire-protected Timber (NCC prescribes FRLs AND non-combustible fire-protective coverings)
Objective: To prevent or delay ignition of the timber structural member so that the response to an enclosure fire will be similar to that for a building constructed on non-combustible elements such as masonry or concrete during the growth period. The fire-protected timber element is still required to achieve the Deemed-to-Satisfy FRLs specified in the NCC.

Cavity Barriers
Objective: To prevent the uncontrolled spread of fire through cavities in the low probability event of either failure of the fire-protective covering or fire start within the cavity.

Further details for the application of the DTS solutions for mid-rise buildings are provided in WoodSolutions Technical Design Guide #37

Non-Combustible Insulation

Objective: To minimise the risk of fire spread through cavities by removing a major fuel source (i.e. combustible insulating materials).

This section provides basic information on the application of the NCC Deemed-to-Satisfy Provisions relating to mid-rise fire-protected timber buildings introduced in the 2016 edition. Further information including typical details are provided in WoodSolutions Technical Design Guide #37 *Mid-rise Timber Buildings* and National Construction Code Volume One 2016.

4.2 Automatic Fire Sprinklers

A key fire safety feature for mid-rise timber buildings is the requirement to provide automatic fire sprinkler systems in accordance with NCC Specification E1.5 throughout the building, including any parts of the building that are not of timber construction. This requirement in conjunction with other fire safety measures is considered to reduce the risk from fires in mid-rise timber buildings below that in other forms of construction complying with the minimum NCC requirements.

4.2.1 Sprinkler Design Standards Permitted by NCC Specification E1.5

Specification E 1.5 allows sprinkler systems to be designed in accordance with

- AS 2118.1:1999 Automatic Fire Sprinkler Systems – General Requirements
- AS 2118.4:2012 Automatic fire sprinkler systems – Sprinkler protection for accommodation buildings not exceeding four storeys in height
- AS 2118.6:2012 Combined sprinkler and hydrant systems in multi-storey buildings.

The scope of AS 2118.4 excludes offices and is limited to accommodation (residential) buildings not exceeding four stories in height. Therefore most mid-rise timber building sprinkler systems will be designed to comply with AS 2118.1 or AS 2118.6.

4.2.2 Designing Fire Sprinkler systems to improve their effectiveness

There are opportunities during the design process to incorporate features that can enhance the effectiveness of an automatic sprinkler system and simplify ongoing maintenance. A few examples of matters for consideration are:

Residential Heads in Residential SOUs and associated corridors

Both AS 2118.1 and 2118.6 allow the use of appropriately listed residential heads in residential building SOUs and associated corridor areas. Residential heads have a more rapid response than standard heads and are more likely to supress rather than control a fire, thus reducing the risk to occupants within the SOU of fire origin. Therefore, residential heads should be specified where appropriate.

Monitored Valves

The reliability of fire sprinkler systems can be enhanced by the provision of monitored components such as main stop valves and subsidiary stop valves. While the NCC provides some requirements for monitored valves, the effectiveness of sprinkler systems can be enhanced by, for example, the specification of monitored stop valves on each floor. This enables sprinkler protection to be maintained throughout the remainder of the building while work is undertaken on part of the sprinkler system and if the valve is left closed upon completion of the work the building owner/operator can be alerted to ensure the error is corrected quickly. Thus the time periods and extent of areas where sprinkler protection is unavailable are minimised. The progressive installation of monitored valves during construction can be used as part of the strategy to address fires during construction by facilitating the progressive commissioning of the sprinkler system.

False Ceilings

If sprinkler pipes are run above a ceiling system that is required to achieve a resistance to the incipient spread of fire (RISF), the ceiling may need to be penetrated to accommodate sprinkler heads, potentially compromising the performance of the ceiling if the sprinkler system fails to operate successfully.

This can be avoided by providing a false ceiling and running the pipes below the RISF ceiling, and the penetrations for the sprinkler heads need only penetrate the non-fire-resisting false ceiling.

This detail also provides flexibility for the installation of lighting systems and other services.

Selection of materials and pipe connections

The use of CPVC piping for sprinkler systems can reduce hot works but, if the pipework needs to be modified, the system may be unavailable; potentially overnight while the adhesive cures. Another option may be the use of mechanical joiners, avoiding the need for hot works and glued connections if components need replacing or modifying.

Protection of voids / concealed spaces

Concealed spaces within fire-protected timber elements greater than 200 mm deep generally require protection in accordance with AS 2118.1 and AS 2118.6. Where these voids include elements such as beams, the void depth is measured from the soffit of the beam.

Where open web beams (trusses) or similar elements are included in the cavity, consideration may be given to providing protection where the distance between a ceiling and the bottom chord is less than 200 mm, since open webs will not obstruct the sprinkler discharge to the same extent as solid beams.

Refer to NCC Spec A1.1 for Fire-protected Timber

4.3 Fire Protected Timber Requirements

The NCC defines fire-protected timber as fire-resisting timber building elements that comply with Specification A1.1.

4.3.1 Fire-Protected Timber – General Requirements

Refer to NCC Spec A2.3 for FRL

Refer to NCC Spec A2.5 for RISF

Refer to NCC Spec A2.2 for non-combustibility

Specification A1.1 applies the following general requirements to fire-protected timber:

- The building element must be protected to achieve the required FRL and have a non-combustible fire-protective covering applied to the timber that achieves a resistance to the incipient spread of fire (RISF) of not less than 45 minutes when tested in accordance with AS1530.4.

Therefore, to adequately specify or check Evidence of Suitability of a fire-protected timber element, three items of information are required:

- Fire resistance level – FRL (determined from AS 1530.4 test or an equivalent or more severe test)
- Resistance to the incipient spread of fire – (RISF) FRL (determined from AS 1530.4 test or an equivalent or more severe test)
- Results from a non-combustibility test in accordance with AS 1530.1 (for materials not deemed non-combustible by the NCC).

Fire Resistance Level (FRL) is the grading period in minutes for the following three criteria expressed in the order listed below separated by forward slashes.

- Structural adequacy – ability of a loadbearing element to support an applied load
- Integrity – ability of an element of construction to resist the passage of flames and hot gases from one space to another
- Insulation – ability of the surface of an element of construction not exposed to the furnace to maintain a temperature below the specified limits.

For example, if an FRL of 90/60/30 is specified, the element would need to satisfy the structural adequacy criteria for 90 minutes, the integrity criteria for 60 minutes and the insulation criteria for 30 minutes. A dash means that there is no requirement for that criterion, i.e. an FRL of 90/-/- means that only the criterion of structural adequacy applies for 90 minutes.

NCC Spec A1.1 includes some Deemed-to-Satisfy fire-protective covering systems based on fire-protective-grade plasterboard

The Resistance to the Incipient Spread of Fire (RISF) in relation to a fire-protective covering means the ability of the covering to insulate voids and the interfaces with timber elements so as to limit the temperature rise to a level that will not permit ignition of the timber and the rapid and general spread of fire throughout any concealed spaces. The performance is expressed as the period in minutes that the covering will maintain a temperature below the specified limits

A material is classified as non-combustible if flaming is not observed and specified temperature rise limits are not exceeded when a sample of material is exposed to the heating conditions specified in AS 1530.1.

To facilitate a consistent approach to specifying the required performance of fire-protected timber, the following format of notation is recommended: Fire-Protected Timber –

FRL90/90/90: RISF45: NC.

This means that the element must satisfy the structural adequacy, integrity and insulation requirements for 90 minutes; the resistance to the incipient spread of fire criteria for 45 minutes; and the fire-protective covering must have been shown to be non-combustible when tested in accordance with AS 1530.1 or be deemed by the NCC to be non-combustible.

While individual test/assessment reports from NATA-registered testing authorities can be used as Evidence of Suitability, it may be more practical for registered testing authorities to provide consolidated reports stating the performance in the above format.

Further information relating to the test procedures to determine the Fire Resistance and Resistance to the Incipient Spread of Fire are provided in Appendix E.

Cavities are permitted within fire-protected timber elements that, without adequate measures in place, can allow fire spread through concealed spaces. The risk of fire spread from enclosure fires to the cavities is substantially reduced by the requirement for an RISF45 applied to the fire-protective covering, among other things, but there is a small residual risk of fire spread to the cavity from an enclosure fire or a fire start within a cavity due to hot works, for example. The risk of fire spread via concealed spaces – should this low probability event occur – is further reduced by the Provisions for cavity barriers and requirements for cavity insulation, if present, to be non-combustible.

Specification A1.1 deems 2 layers of 13 mm fire-protective-grade plasterboard fixed in accordance with the requirements to achieve the required FRL of the element to achieve equivalent performance to an RISF45: NC fire-protective covering.

Thus the timber-framed wall system shown in Figure 4.2 with two layers of 13 mm fire-protective plasterboard either side of a cavity between studs could be classified as Fire-Protected Timber – FRL90/90/90: RISF45: NC; if the loadbearing wall system had achieved an FRL of 90/90/90 under similar or more severe load conditions in an AS 1530.4 fire test, since two layers of 13 mm fire-grade plasterboard are deemed to achieve an RISF45 and plasterboard is deemed NC by the NCC.

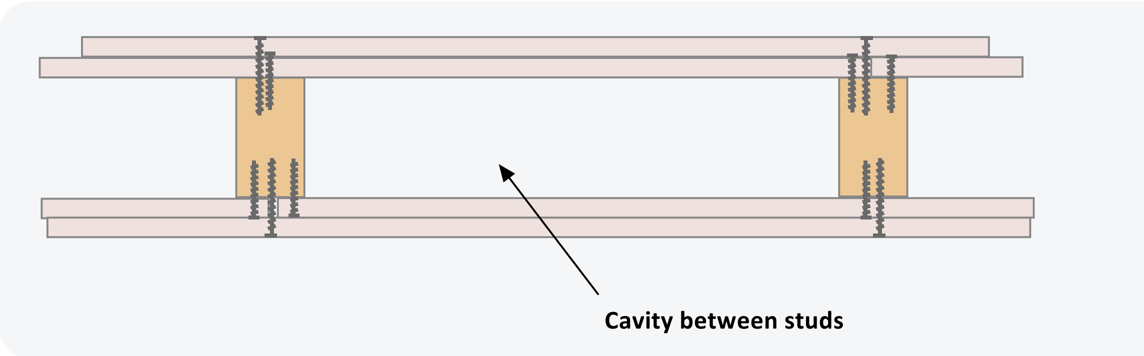


Figure 4.2: Horizontal section through typical FRL90/90/90:RISF45: NC timber stud wall.

The primary objective for the inclusion of the non-combustibility requirement for the fire-protective covering is so that the reaction to fire performance of the fire-protected timber to external and enclosure fires is comparable to elements of construction that are non-combustible; such as reinforced concrete or steel protected with non-combustible materials.

The primary objective for the specification of RISF45 is to reduce the risk of the timber structural elements being ignited prior to burn-out of the contents or fire brigade intervention, in the unlikely event of failure of the automatic fire sprinkler system. To achieve this objective, it is necessary for the RISF performance not to be compromised by the presence of building service penetrations and openings for doors and windows. See Section 4.9.3 and Appendix E for further details on how the RISF performance can be maintained though appropriate penetration fire stopping systems, cavity barriers and lining of openings.

4.3.2 Massive Timber

The NCC permits a 'relaxation' of the general requirements for fire-protected timber, provided both the following additional criteria are satisfied:

- The minimum timber thickness of timber panels is not less than 75 mm.
- There are no cavities between the surface of the timber and the fire-protective covering system.

The 75 mm dimension relates to the minimum dimension of the dressed or finished timber member. In most instances, massive timber elements will have minimum thicknesses much greater than 75 mm to meet the structural adequacy and integrity criteria of AS 1530.4.

Typical examples of massive timber panel installations satisfying the conditions for this provision to apply are shown in Figure 4.3.

The reasons for modifying the fire-protected timber requirements for massive timber are:

1. Timber members having a large cross-section can achieve high fire resistance levels due to the formation of a char that protects the timber core, allowing it to continue to support an imposed load or maintain a fire separating function for significant periods. Therefore if there is an early failure of the fire-protective covering, the timber structure is likely to maintain its loadbearing capacity for a greater period than light-weight construction.
2. By not permitting any concealed spaces between the timber members or between the timber and fire-protective coverings, the risk of fire spread through concealed cavities is addressed.

If the massive timber conditions are satisfied, the following requirements can be adopted for fire-protected timber in lieu of the general requirements:

- The building element must be protected to achieve the required FRL.
- The building element must have a non-combustible fire-protective covering applied to the timber that achieves the modified resistance to the incipient spread of fire (MRISF) of not less than the values stated in Table 4.1, when tested in accordance with AS1530.4.

The modified resistance to spread of fire is determined in accordance with Clause 3 of NCC Specification A1.1. Further information relating to the test procedures to determine the Fire Resistance and Modified Resistance to the Incipient Spread of Fire are provided in Appendix E.

To facilitate a consistent approach to specifying the required performance of fire-protected timber, the following format of notation is recommended:

Fire-Protected Timber - FRL 90/90/90: MRISF 30: NC.

This means that the element must satisfy the structural adequacy, integrity and insulation requirements for 90 minutes; the modified resistance to the incipient spread of fire criteria for 30 minutes; and the fire-protective covering must have been shown to be non-combustible when tested in accordance with AS 1530.1 or be deemed by the NCC to be non-combustible.

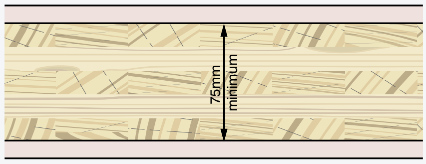
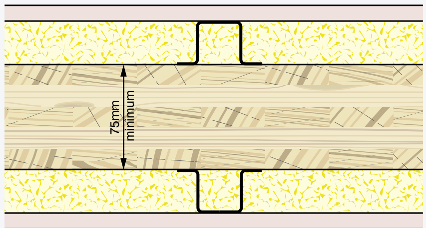
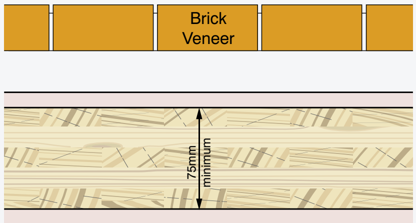
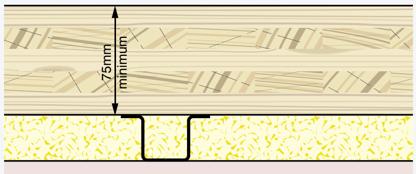
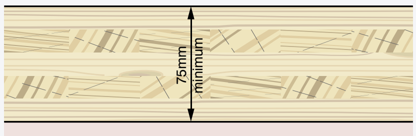
Description	Schematic section
Massive Timber Wall Panels	
Direct fix to massive timber panel.	
Fire-protective covering fixed to solid timber battens with non- combustible insulation - both sides of a wall panel.	
External Brick veneer wall- Note massive timber is faced on both sides with fire protective coverings allowing an unobstructed cavity	
Massive Timber Floor Panels	
Fire-protective covering fixed to furring channels om the underside of a floor panel with non- combustible insulation.	
Fire-protective covering direct fix to massive timber panel.	

Figure 4.3: Massive timber details qualifying under the massive timber provisions.

Refer to NCC Volume One Specification C1.1 for required FRLs and Specification A1.1. for RISF requirements

Table 4.1: Fire-protective covering requirements – massive timber.

Application	Modified Resistance to the Incipient Spread of Fire (MRISF)	Minimum Deemed-to-Satisfy Fire-protective Grade Plasterboard
Inside a fire-isolated stairway or lift shaft	20 min	1 layer x 13mm thick
External walls within 1 m of an allotment boundary or 2 m of a building on the same allotment	45 min	2 layers x 13mm thick
All other applications	30 min	1 layer x 16mm thick

Table 4.1 also includes Deemed-to-Satisfy fire-protective grade plasterboard minimum requirements if fixed in accordance with the requirements to achieve the required FRL of the element for massive timber.

For example, if a non-loadbearing wall system is required to achieve an FRL of -/60/60, an appropriate specification for an element using the massive timber provisions would be:

Fire-Protected Timber FRL -/60/60: MRISF 30: NC

If there is appropriate Evidence of Suitability to show a massive timber element can achieve an FRL of -/60/60 when protected by 16 mm fire-protective plasterboard, then no further evidence is required, since the 16 mm thick plasterboard is Deemed-to-Satisfy the MRISF 30 requirement and the plasterboard is also deemed to be non-combustible.

4.3.3 Fire-protected Timber Element Requirements for Mid-Rise Class 2 or 3 Buildings of Timber Construction (General Requirements)

Mid-rise Class 2 and 3 (residential buildings) are typically more than 3 storeys high and are therefore required to be of Type A construction by NCC Volume One. On this assumption, the fire-protected timber requirements for various wall, floor, ceiling and other building elements are given in Table 4.2 for the typical mid-rise timber apartment building shown schematically in Figure 4.4 and Figure 4.5.

The requirements for external walls are given in Section 4.6.

Refer Specification C1.1 of NCC Volume One Cl 3.5 for the roof concession

Table 4.2: FRL and RISF general requirements for timber-framed mid-rise apartment buildings.

Symbol	Description	FRL – Structural Adequacy /Integrity/ Insulation - min		Resistance to the Incipient Spread of Fire (min.)
		Loadbearing	Non–loadbearing	
	Fire stair shaft	90/90/90	-/90/90	45
	Service shaft	90/90/90	-/90/90	45
	Bounding Sole Occupancy Units	90/90/90	-/60/60	45
	Lift shaft walls	90/90/90	-/90/90	45
	Door to fire stair	Not applicable	-/60/30	Not applicable
	Fire door to service shaft	Not applicable	-/60/30	Not applicable
	Door to SOU	Not applicable	-/60/30	Not applicable
	Lift door	Not applicable	-/60/-	Not applicable
	Doors to services risers	Not applicable	-/60/30	Not applicable
	Non-loadbearing walls within an apartment	Not applicable	-/-/-	-
	Floors	90/90/90	Not applicable	45

Note: Since the roof will have a non-combustible covering and mid-rise timber buildings are required to be sprinkler protected throughout, the roof is not required to achieve an FRL.

In addition to the above requirements, the fire-protective coverings must also be non-combustible.

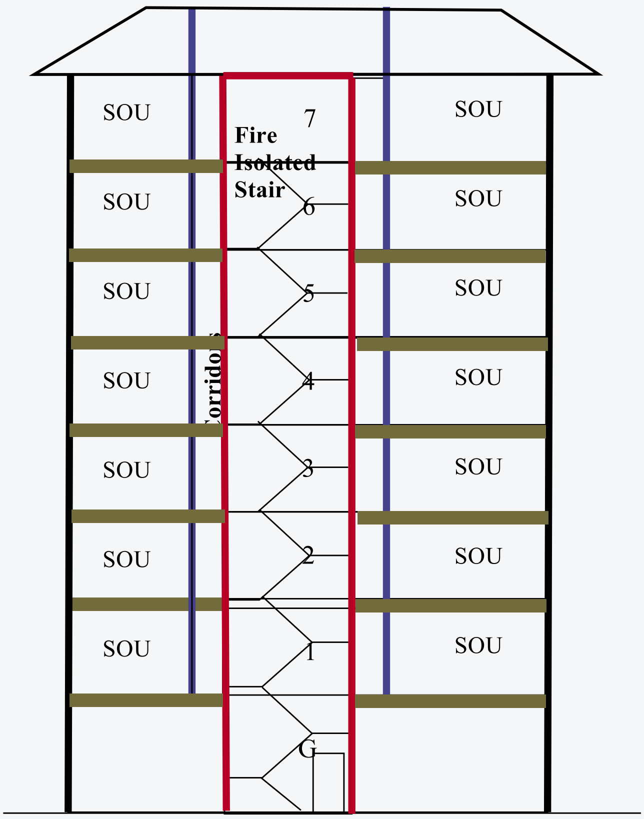


Figure 4.4: Typical section through a mid-rise apartment building.

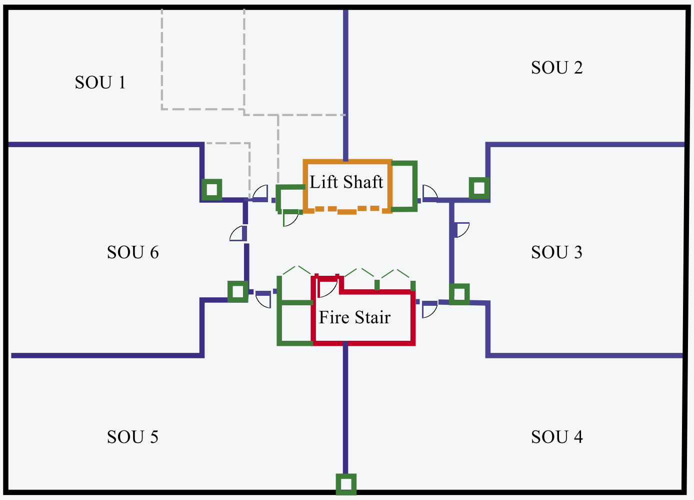


Figure 4.5: Plan of a typical apartment building floor.

Refer to NCC Volume One Specification C1.1 for required FRLs and Specification A1.1. for MRISF requirements

4.3.4 Fire-protected Timber Element Requirements for Mid-rise Class 2 or 3 Buildings of Timber Construction for Massive Timber

The massive timber provisions can only be applied if both the minimum member size and cavity restrictions are satisfied. If these conditions are not fully satisfied for an element then the general requirements must be applied as summarised in Section 4.3.3 above.

A typical mid-rise timber apartment building layout is shown in Figure 4.4 and Figure 4.5 with fire-protected timber elements. The FRLs and MRISF requirements for these elements are summarised in Table 4.3 for applications where the massive timber provisions can be applied. For external walls see Section 4.6.

Table 4.3: FRL and MRISF Requirements for timber mid-rise apartment buildings if the massive timber provision is applicable.

Symbol	Description	FRL – Structural Adequacy /Integrity/ Insulation – min		Modified Resistance to Incipient Fire Spread – min
		Loadbearing	Non-loadbearing	
	Fire stair shaft	90/90/90	-/90/90	30 outside 20 inside
	Service shaft	90/90/90	-/90/90	30
	Bounding Sole Occupancy Units	90/90/90	-/60/60	30
	Lift shaft walls	90/90/90	-/90/90	30
	Door to fire stair	Not applicable	-/60/30	30 outside 20 inside
	Fire door to service shaft	Not applicable	-/60/30	Not applicable
	Door to SOU	Not applicable	-/60/30	Not applicable
	Lift door	Not applicable	-/60/-	Not applicable
	Doors to services risers	Not applicable	-/60/30	Not applicable
	Non-loadbearing walls within an apartment	Not applicable	-/-/-	-
	Floors	90/90/90	Not applicable	30

Note: Since the roof will have a non-combustible covering and mid-rise timber buildings are required to be sprinkler protected throughout, the roof is not required to achieve an FRL.

In addition to the above requirements the fire-protective coverings must also be non-combustible

Refer to Specification C1.1 of NCC Volume One Cl 3.5 for the roof concession

4.3.5 Fire-protected Timber Element Requirements for Mid-rise Class 5 Buildings of Timber Construction (General Requirements)

Mid-rise Class 5 (office buildings) are typically 3 or more storeys high. Three-storey office buildings are generally of Type B construction and those greater than three storeys of Type A construction.

The element requirements for timber-framed mid-rise Class 5 buildings are given in Table 4.4 for Types A and B construction.

The requirements for external walls are given in Section 4.6.

Table 4.4: FRL and RISF general requirements for timber-framed mid-rise office buildings.

Description	FRL – Structural Adequacy /Integrity/Insulation – min				Resistance to the Incipient Spread of Fire (min)
	Type A Construction		Type B Construction		
	Loadbearing	Non-Loadbearing	Loadbearing	Non-Loadbearing	
Common walls and Fire walls	120/120/120	Not applicable	120/120/120	Not applicable	45
Fire stair shaft	120/120/120	-/120/120	120/120/120	-/120/120	45
Service Shaft	120/90/90	-/90/90	Not applicable	Not applicable	45
Bounding walls – SOUs, public corridors etc	120/-/-	-/-/-	120/-/-	-/-/-	45
Lift Shaft walls	120/120/120	-/120/120	120/120/120	-/120/120	45
Door to fire Stair	Not applicable	-/60/30	Not applicable	-/60/30	Not applicable
Fire Door to service shaft	Not applicable	-/60/30	Not applicable	-/60/30	Not applicable
Lift door	Not applicable	-/60/-	Not applicable	-/60/-	Not applicable
Other Loadbearing internal walls, internal beams trusses and columns	120/-/-	Not applicable	120/-/- (Other Loadbearing internal walls and columns only)	Not applicable	45
Floors/Beams	120/120/120	Not applicable	120/-/-[1]	Not applicable	45

Note 1: It has been assumed the floors support loadbearing columns and/or walls and therefore the same FRL, as the part they support, applies.

Refer to NCC Volume One Specification C1.1 for required FRLs and Specification A 1.1. for MRISF requirements

4.3.6 Fire-protected Timber Element Requirements for Mid-rise Class 5 Buildings of Massive Timber Construction

The massive timber provisions can only be applied if both the minimum member size and cavity restrictions are satisfied. If these conditions are not fully satisfied for an element, then the general requirements must be applied as summarised in Section 4.3.5 above.

The FRLs and MRISF requirements applicable to fire-protected timber elements in office buildings are summarised in Table 4.5 for applications where the massive timber provisions can be applied. For external walls see Section 4.6.

Table 4.5: FRL and MRISF requirements for massive timber mid-rise office buildings

Description	FRL – Structural Adequacy /Integrity/Insulation – min				Modified Resistance to the Incipient Spread of Fire
	Type A Construction		Type B Construction		
	Loadbearing	Non-Loadbearing	Loadbearing	Non-Loadbearing	
Common walls and Fire walls	120/120/120	Not applicable	120/120/120	Not applicable	30
Fire stair shaft	120/120/120	-/120/120	120/120/120	-/120/120	30 outside 20 inside
Service Shaft	120/90/90	-/90/90	Not applicable	Not applicable	30
Bounding walls – SOUs, public corridors etc	120/-/-	-/-/-	120/-/-	-/-/-	30
Lift Shaft walls	120/120/120	-/120/120	120/120/120	-/120/120	30 outside 20 inside
Door to fire Stair	Not applicable	-/60/30	Not applicable	-/60/30	Not applicable
Fire Door to service shaft	Not applicable	-/60/30	Not applicable	-/60/30	Not applicable
Lift door	Not applicable	-/60/-	Not applicable	-/60/-	Not applicable
Other Loadbearing internal walls, beams and trusses	120/-/-	Not applicable	120/-/- (Other loadbearing internal walls and columns only)	Not applicable	30
Floors	120/120/120	Not applicable	120/-/-[1]	Not applicable	30

Note 1: It has been assumed the floors support loadbearing columns and/or walls and therefore the same FRL, as the part they support, applies.

4.4 Cavity Insulation Requirements

Refer to NCC Volume One Specification A1.1. Cl 2.3

If cavity insulation is provided within fire-protected timber elements it is required to be non-combustible. Combustible cavity insulation can facilitate ignition of cavity fires and the rapid spread of fire through cavities.

Typical solutions include mineral fibre or glass wool insulation with very low organic binder contents. It is therefore important to check that Evidence of Ssuitability in the form of a current AS 1530.1 report from a NATA-registered testing authority is available for the specific products selected.

4.5 Cavity Barrier Requirements

Cavity barriers are defined in the NCC as a barrier placed in a concealed space, formed within or around the perimeter of fire-protected timber building elements that complies with Specification C1.13; to limit the spread of fire, smoke and hot gases to other parts of the building.

They are required to be provided by the following clauses as part of a prescribed solution:

- Clause C1.13 Fire-protected timber concession
- Clause 3.1 d (iii) of Specification C1.1
- Clause 4.1 e (iii) of Specification C1.1

The use of fire-protected timber in mid-rise buildings is based on the following principles:

(a) reducing the risk of timber structural elements becoming involved in a fire by the use of fire-protective coverings in conjunction with automatic fire sprinklers, and

(b) in the low probability of fire spreading to cavities/voids, or of a fire developing within a cavity, limiting that spread by cavity barriers in conjunction with other measures such as the use of non-combustible cavity insulation.

The risk of fire spread via cavities and voids in designs that use the massive timber provisions is addressed by prohibiting designs that incorporate cavities and voids.

4.5.1 Determining the Positions of Cavity Barriers

Cavity barriers are required at the following positions:

- around the perimeter of fire-protected timber elements
- junctions between fire-resisting floor/ceiling assemblies and fire-resisting walls
- junctions between fire-resisting floor/ceiling assemblies and fire-resisting external walls
- junctions between fire-resisting walls and external walls
- around the perimeters of door and window openings in fire-resisting construction
- horizontal barriers at each floor level with a maximum distance of 5 m between horizontal cavity barriers
- vertical cavities must be provided in walls at maximum of 10 m centres.

Typical positions of cavity barriers are shown for an apartment building in Figure 4.6 and Figure 4.7. A key describing the types of interface being protected is included in Table 4.6.

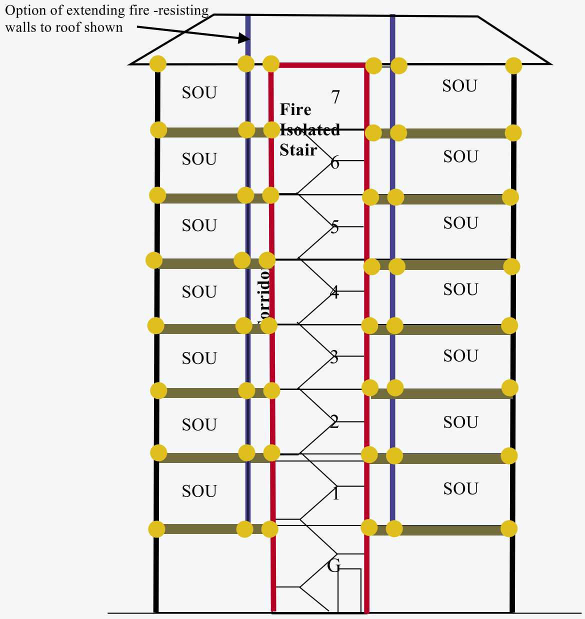


Figure 4.6: Vertical section of an apartment building showing typical cavity barrier positions.

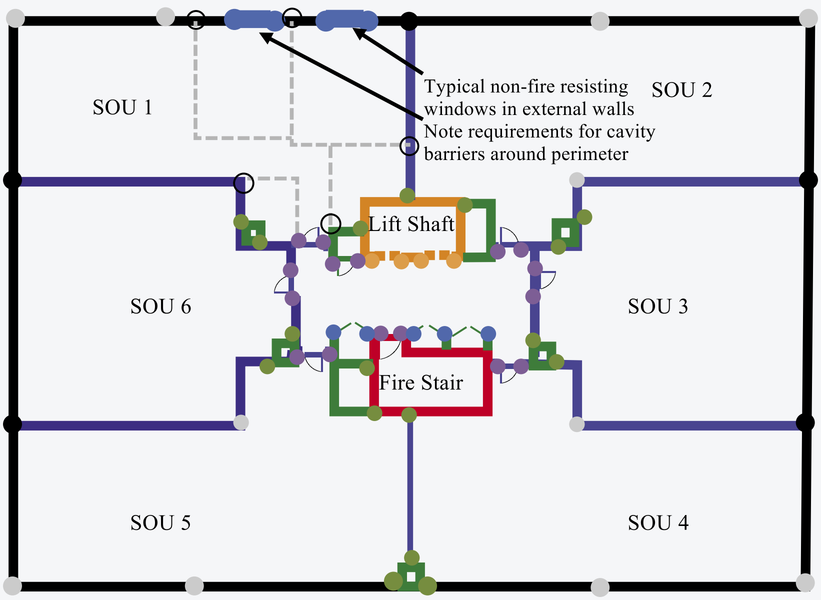


Figure 4.7: Horizontal section of an apartment building showing typical cavity barrier positions.

Table 4.6: Key to cavity barrier positions.

Symbol	Description	Comments
	Horizontal cavity barriers around perimeter of floors	If floor to floor height greater than 5m intermediate horizontal barriers in walls would be required
	Cavity barriers in fire-protected timber walls	Vertical cavity barriers are required at maximum 10m centres
	Cavity barriers around perimeter of non fire resistant doors and windows	Required to prevent entry of fire into cavity when non-fire resistant elements fail
	Interface of fire resistant walls with external walls	Can be incorporated as part of a standard detail
	Interface of shafts with standard walls	Can be incorporated as part of a standard detail
	Interface with fire doors	Normally part of the standard detail for installation since the doorset is required to maintain the fire resistance of the wall
	Interface with lift doors	In some instances it may be more practical to interface with other forms of construction around lift doors
	Interface between non-fire-resisting wall and fire resisting walls	Continuity of the fire-protective coverings should be maintained at the point of penetration

4.5.2 Specifying Cavity Barrier Requirements for Building Elements

Essentially there are two levels of performance required for cavity barriers prescribed by the NCC.

- Cavity barriers with FRLs of -/45/45 for building elements with FRLs up to 90/90/90.
- Cavity barriers with FRLs of -/60/60 for building elements with FRLs greater than 90/90/90 but less than or equal to 120/120/120.

For each of these cases, the NCC prescribes Deemed-to-Satisfy solutions based on minimum thicknesses of timber or mineral fibre in the direction of heat flow as summarised in Table 4.7.

Table 4.7: NCC-prescribed Deemed-to-Satisfy solutions for cavity barriers.

Prescribed solution options	Fire-protected timber FRL	
	90/90/90 or less	>90/90/90 to ≤ 120/120/120
FRL for cavity barrier	-/45/45	-/60/60
Timber – required minimum thickness	45 mm	55 mm
Mineral wool – required minimum thickness	45 mm	60 mm

For fire-protected timber with large cavities, which may occur in floor and roof cavities, for example, it may be more practical to construct cavity barriers from plasterboard supported from timber framing.

Further information relating to the test procedures to determine the Fire Resistance and Modified Resistance to the Incipient Spread of Fire is provided in Appendix E.

4.6 External Walls/Building Façades

In addition to maintaining loadbearing capacity when subjected to fires within a building, the external walls also need to address the risk of fire spread via the building façade under the following scenarios:

- Fire spread from adjacent buildings (or the fire source feature as defined in the NCC) to the subject building. Under the Deemed-to-Satisfy solution pathway for mid-rise timber buildings, this is addressed by means of specification of minimum separation distances, fire-resisting construction and the requirement for external walls to be non-combustible or of fire-protected timber construction.
- Fire spread from the subject building to adjacent buildings (or the fire source features defined in the NCC). Under the Deemed-to-Satisfy solution pathway for mid-rise timber buildings, this is addressed by means of specification of minimum separation distances, fire-resisting construction and the requirement for external walls to be non-combustible or of fire-protected timber construction and the provision of automatic fire sprinklers.
- Fire spread from an external fire source adjacent to the façade other than adjacent structures including balcony fires. Under the Deemed-to-Satisfy solution pathway for mid-rise timber buildings, this is addressed by means of specification of fire-resisting construction and the requirement for external walls to be non-combustible or of fire-protected timber construction.
- Vertical fire spread between openings from a fully developed fire within the subject buildings. Under the Deemed-to-Satisfy solution pathway for mid-rise timber buildings, this is addressed by means of specification of fire-resisting construction and the requirement for external walls to be non-combustible or of fire-protected timber construction and the provision of automatic fire sprinklers.

The measures described above are considered in more detail in the following sections.

4.6.1 Fire-Protected Timber Requirements for External Walls

The FRLs required for external walls are nominated in NCC Specification C1.1 and are dependent on the building use (Class of Building), Type of Construction and proximity to the boundary (fire source feature) or other buildings. Mid-rise residential buildings (Class 2 and 3) are required to be of Type A construction and, while most mid-rise office buildings are also required to be of Type A construction, Type B construction is permitted for 3-storey mid-rise office buildings.

The resistance to the incipient spread of fire (RISF) or, if the massive timber provision is applicable – the modified resistance to the incipient spread of fire (MRISF), requirements are nominated in NCC Specification A1.1.

The requirements for Class 2, 3 and 5 buildings of Type A construction are summarised in Table 4.8 and Table 4.9.

Table 4.8: FRL and RISF general requirements for timber-framed mid-rise residential and office building external walls (Type A construction).

Distance from Fire Source Feature	FRL - Structural Adequacy/Integrity/Insulation – min				Resistance to the incipient fire spread – min
	Class 2 and 3 (Residential)		Class 5 (Office)		
	Loadbearing	Non-loadbearing	Loadbearing	Non-loadbearing	
≤1.0 m	90/90/90	-/90/90	120/120/120	-/120/120	45
<1.5 m	90/90/90	-/90/90	120/120/120	-/120/120	45
≥1.5 and <3 m	90/60/60	-/60/60	120/90/90	-/90/90	45
≥3 m	90/60/30	-/-/-	120/60/30	-/-/-	45
External Columns	90/-/-	-/-/-	120/-/-	-/-/-	45

It should be noted that even though non-loadbearing external walls do not require an FRL if more than 3 m from a fire source feature, the fire-protective coverings must be applied and are required to achieve a RISF of 45 minutes, since the external wall is required to be non-combustible to address the risk of external fires on balconies or external areas adjacent to the building and the risk of vertical fire spread through openings if a fully developed fire occurs.

Table 4.9: FRL and MRISF requirements for massive timber mid-rise residential and office building external walls (Type A construction).

Distance from Fire Source Feature	**FRL - Structural Adequacy/Integrity/Insulation – min**				**Modified Resistance to theIncipient Fire Spread - min**
	Class 2 and 3 (Residential)		**Class 5 (Office)**		
	Loadbearing	**Non-loadbearing**	**Loadbearing**	**Non-loadbearing**	
≤1.0 m	90/90/90	-/90/90	120/120/120	-/120/120	45 external 30 internal
<1.5 m	90/90/90	-/90/90	120/120/120	-/120/120	30
≥1.5 and <3 m	90/60/60	-/60/60	120/90/90	-/90/90	30
≥3 m	90/60/30	-/-/-	120/60/30	-/-/-	30
External Columns	90/-/-	-/-/-	120/-/-	-/-/-	30

It should also be noted that, even though non-loadbearing external walls do not require an FRL if more than 3 m from a fire-source feature, the fire-protective coverings must be applied and are required to achieve a MRISF of 30 minutes.

For buildings within 1 m of the boundary (or 2 m of an adjacent building on the same allotment) an MRISF of 45 minutes for the external surfaces is required to minimise the risk of ignition from fires in adjacent buildings but the internal face need only achieve a MRISF of 30 minutes.

The required FRLs for external walls of 3-storey office buildings (Type B) construction are less than the requirements for Type A construction at distances greater than 1.5 m from the fire source feature. The general requirements are summarised in Table 4.10 and the requirements where the massive timber provision applies are summarised in Table 4.11.

Table 4.10: FRL and RISF general requirements for timber-framed mid-rise office building external walls (Type B Construction).

Distance from Fire Source Feature	**FRL-Structural Adequacy /Integrity/Insulation – min**		**Resistance to the Incipient Spread of Fire – min**
	Loadbearing	**Non-loadbearing**	
≤1.0 m	120/120/120	-/120/120	45
<1.5 m	120/120/120	-/120/120	45
≥1.5 and <3 m	120/90/60	-/90/60	45
≥3 m and <9 m	120/30/30	-/-/-	45
≥9 m and <18 m	120/30/-	-/-/-	45
≥18 m	-/-/-	-/-/-	45
External Columns <18 m	120/-/-	-/-/-	45
External Columns ≥18 m	-/-/-	-/-/-	45

Refer to NCC Volume One Cl C2.6

Refer to NCC Volume One Spec C1.1 Cl 3.1(b) and Cl4.1(b)

Table 4.11: FRL and MRISF requirements for massive timber mid-rise office building external walls (Type B construction).

Distance from Fire Source Feature	FRL - Structural Adequacy /Integrity/Insulation - min		Modified Resistance to the Incipient Fire Spread - min
	Loadbearing	Non–loadbearing	
≤1.0 m	120/120/120	-/120/120	45 external 30 internal
<1.5 m	120/120/120	-/120/120	30
≥1.5 and <3 m	120/90/60	-/90/60	30
≥3 m and <9 m	120/30/30	-/-/-	30
≥9 m and <18 m	120/30/-	-/-/-	30
≥18 m	-/-/-	-/-/-	30
External Columns <18 m	120/-/-	-/-/-	30
External Columns ≥18 m	-/-/-	-/-/-	30

4.6.2 Vertical Separation of Openings in External Walls

The NCC Deemed-to-Satisfy solution for external walls requires vertical separation of openings to be addressed in buildings of Type A construction to reduce the risk of fire spread between floors if a fully developed fire occurs.

This can be achieved by the provision of spandrel panels or horizontal projections but the NCC waives these requirements if an automatic fire sprinkler system is provided in accordance with NCC Spec E1.5. This recognises that early suppression or control of an internal fire by an automatic fire sprinkler system is an effective means of minimising the risk of fire spread between floors via the façade.

The Deemed-to-Satisfy solution for mid-rise timber buildings requires the building to be provided with a sprinkler system complying with E1.5 installed throughout the building and therefore there is no need to provide additional vertical separation by, for example, the provision of spandrel panels. This simplifies construction and provides greater design flexibility.

4.6.3 External Wall/Façade Systems

External walls form the building façade and are required to serve a number of functions by the NCC in addition to addressing fire safety. These include:

- structural performance – for safety and serviceability
- weather resistance – (resistance to water penetration)
- light and ventilation (including condensation control)
- energy efficiency (thermal insulation)
- durability
- acoustic separation.

The external face of the wall may form part of the fire-protective covering, e.g. brick veneer construction, or may cover a fire-protective covering to prevent water penetration and serve other non-fire-related functions. In both cases, the NCC requires the external walls to be of non-combustible construction and therefore these coverings must be non-combustible.

If the design brief proposes the use of combustible cladding systems, the performance pathway could be adopted subject to it being able to demonstrate compliance of the wall system with the relevant NCC performance requirements.

4.7 Lift Shafts

Some designs of timber buildings adopt a hybrid approach and incorporate concrete or masonry shafts. Where this approach is adopted, it is important for the potential for differential movement between the timber structure and shaft to be taken into account when detailing connections and interfaces.

When designing lift shafts, it is important to involve the lift supplier at an early stage to ensure the shaft will satisfy their design requirements and applicable regulations.

The remainder of this section will address the fire safety performance of lift shafts of fire-protected timber construction with respect to NCC compliance.

4.7.1 Timber-framed Lift Shaft Construction

Table 4.12 has been derived from Section 4.3 to show the NCC requirements that are applicable to timber-framed lift shafts in mid-rise timber buildings.

Table 4.12: Requirements for fire-protected timber-framed lift shafts.

Criteria	Residential Buildings (Class 2 and 3)	Office Buildings
FRL for loadbearing walls	90/90/90	120/120/120
FRL for non-loadbearing walls	-/90/90	-/120/120
RISF for walls	45	45
Lift landing doors	-/60/-	-/60/-

Further details are provided in WoodSolutions Technical Design Guide #37

The wall FRL and RISF requirements are applicable from both within and outside the shaft.

To minimise sound transmission to adjoining areas, double stud construction may be employed and/or an independent lift support structure provided within the shaft.

The fire resistance of lift landing door assemblies should be determined by undertaking fire tests in a representative wall construction type. At the time of preparation of this Guide, few lift landing doors have been tested in timber-framed wall assemblies.

A practical way to address this is to transition the shaft wall construction around the door opening to a form of non-combustible construction, having FRLs that the performance of the lift door has been already verified in.

An example of transitioning to a steel shaft wall system from a fire-protected timber wall shaft is shown in Figure 4.8 and Figure 4.9.

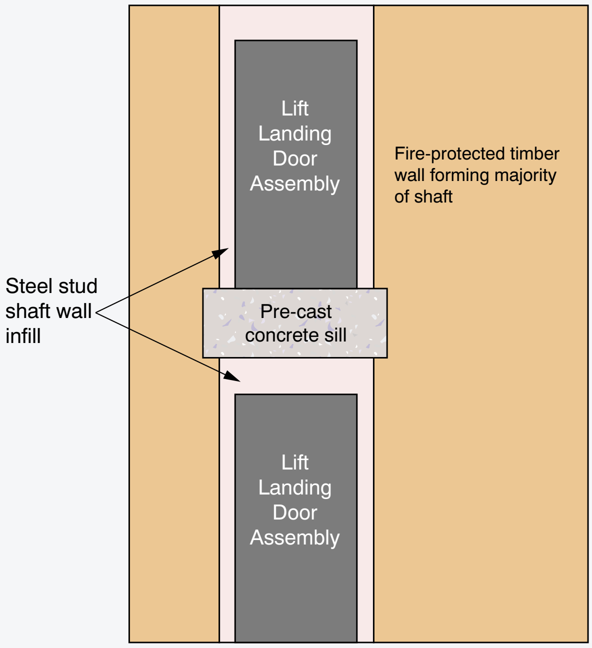


Figure 4.8: Elevation showing wall transition around lift landing doors.

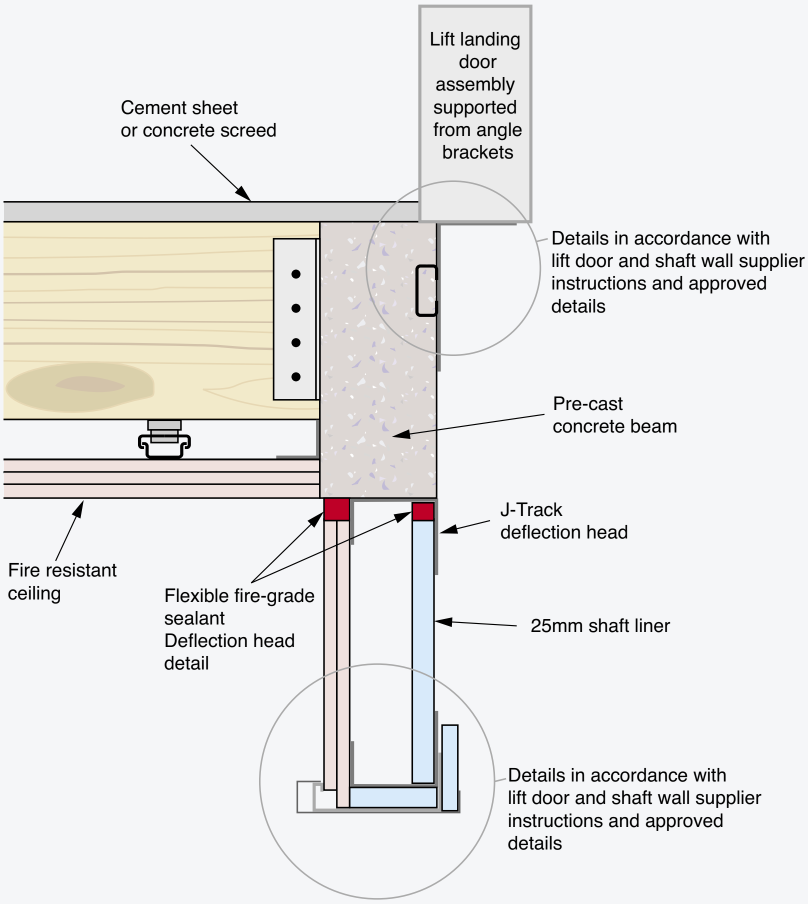


Figure 4.9: Generic detail for sill and head mounting.

4.7.2 Massive Timber Lift Shaft Construction

Table 4.13 has been derived from Section 4.3 to show the NCC requirements that are applicable to timber lift shafts in mid-rise timber buildings if the massive timber provision is applicable.

Table 4.13: Requirements for fire-protected timber lift shafts if the massive timber provision applies.

Criteria	Residential Buildings (Class 2 and 3)	Office Buildings Class 5
FRL for loadbearing walls	90/90/90	120/120/120
FRL for non-loadbearing walls	-/90/90	-/120/120
RISF for walls	30 outside face 20 inner face	30 outside face 20 inner face
Lift landing doors	-/60/-	-/60/-

If the massive timber provision applies, the MRISFs are reduced from 30 minutes to 20 minutes within the lift shaft. This relaxation reflects the lower probabilities of severe fires within these areas but a basic level of protection is retained since, if fires occur within these areas, evacuation paths from the buildings could be quickly compromised due to rapid fire spread in the early stages of a fire. The outer faces still require an MRISF of 30 minutes - refer Figure 4.10.

To minimise sound transmission to adjoining areas, double leaf construction may be employed and/or an independent support structure provided within the shaft. If double leaf construction is employed, the general requirements require the inner and outer faces to achieve a RIFS of 45 minutes. This can be achieved by applying two layers of 13 mm thick fire-protective-grade plasterboard to both the inner and outer faces of the shaft.

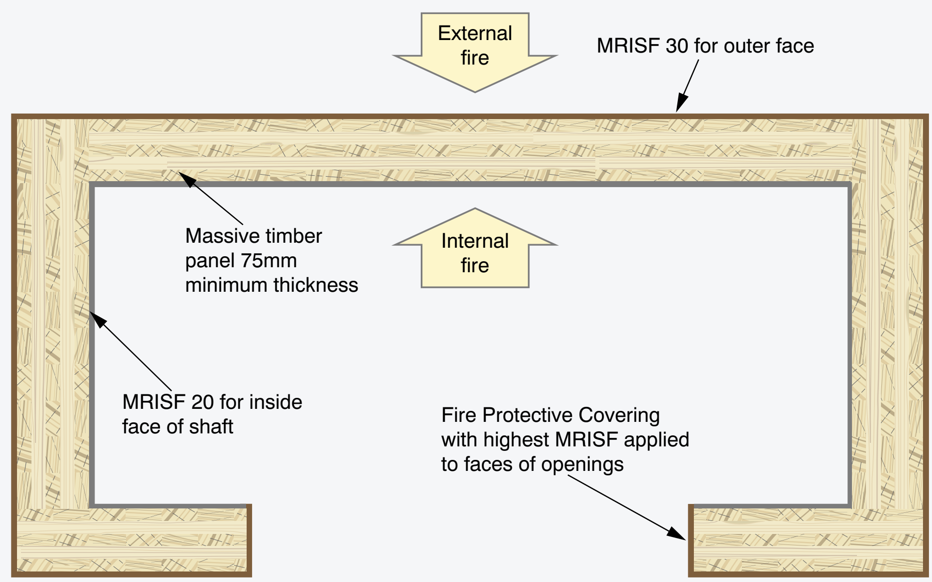


Figure 4.10: Lift shaft MRISF requirements if the massive timber provisions apply.

4.8 Fire-isolated Stairs and Passageways

4.8.1 Fire-isolated Stair and Passageway Construction

The FRLs, RISFs or MRISFs required for fire-isolated stairs and passageways are the same as those required for lift shafts described in Section 4.7.

Fire doors to fire-isolated stairs or passageways are required to achieve an FRL of -/60/30. Several proprietary fire door systems have been tested when mounted in timber construction. Installation details for fire doors capable of achieving FRLs of -/60/30 or above should be obtained from the supplier, since they may vary. Figure 4.11 shows a typical interface detail with a fire-protected timber wall.

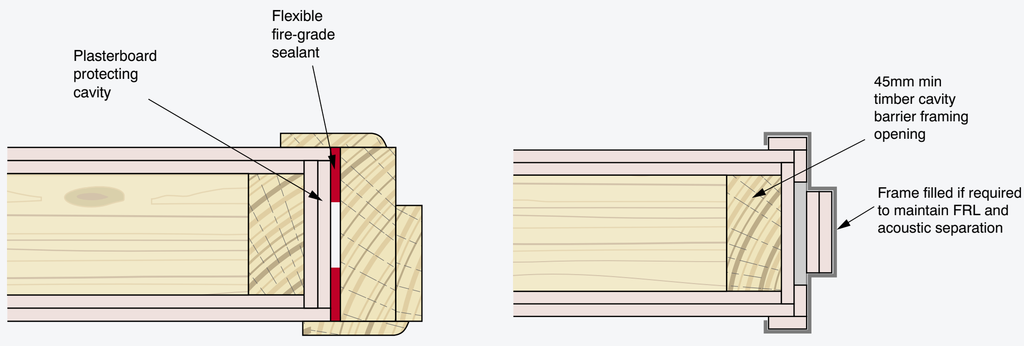


Figure 4.11: Typical fire door installation details.

4.8.2 Timber Stairways Concession

NCC Clause D2.25 provides a concession allowing timber treads, risers, landings and associated supporting framework to be used within a required fire-isolated stairway or fire-isolated passageway subject to:

a) the building being protected throughout by a sprinkler system complying with Specification E1.5 which is extended to provide coverage within the fire-isolated enclosure; and

b) the underside of flights of stairs directly above landings providing access to ground level or car parking levels being protected by a single layer of 13 mm fire-protective-grade plasterboard fixed to the stringers with fixings at not greater than 150 mm centres.

While fire starts in fire-isolated stairs are rare, when they do occur they generally involve stored or introduced materials and often the cause is malicious. While goods are not permitted to be stored in fire-isolated stairs and passageways, areas under the lowest flight of stairs form a convenient dry area for temporary storage. These areas may also not be secured, further increasing the risk of malicious fire starts.

While it could be argued that the extension of the sprinkler system to fire-isolated stairs and passageways addresses this issue, as an additional precaution, the underside of the lower stairs and landing where combustibles could be stored are required to be protected by a fire-protective covering of 13 mm fire-protective-grade plasterboard.

Typical generic details for treating service penetrations are provided in WoodSolutions Technical Design Guide #37

4.9 Building Services

4.9.1 Selection of Building Services and Distribution Paths

The building services and associated cable and pipe runs need to be selected and refined throughout the design process, to ensure the installation of the services and associated fire protection systems is efficient and reliable, and access is provided so the systems can be maintained or be expanded safely, without compromising fire safety systems.

Key points for consideration with respect to fire safety and acoustics are:

The number of service penetrations through fire-protected timber construction and fire-resisting construction generally should be minimised, as far as practicable. This can be achieved by measures such as the use of self-contained air conditioning systems serving each SOU, the use of false ceilings and wall facings allowing services to run behind the non-fire-rated face without penetrating the fire-resisting elements.

Services and connection details that do not require hot works should be selected where practicable to minimise the time fire services such as sprinkler systems will be unavailable. In some instances these requirements may conflict. For example, the use of CPVC piping for sprinkler systems can reduce hot works but the system will be unavailable if the pipework is adjusted – potentially overnight while the adhesive sets. Another option may be the use of mechanical joiners, avoiding the need for hot works or lengthy periods that the sprinkler system is unavailable while adhesives cure.

If service penetrations through fire-resisting construction cannot be avoided, the services should preferably penetrate shaft or service duct walls rather than fire-resisting walls or floors separating occupied areas. This reduces the acoustic impact as well as limiting the consequences if a penetration protection system fails; since smoke and fire spread will initially be limited to the service ducts.

Where practicable, shafts, service risers and service ducts should be readily accessible from public parts of the building to facilitate maintenance and inspection, but access hatches, panels or doors providing access should be secured to prevent unauthorised access.

If service penetrations through fire-protected timber construction cannot be avoided, where practicable, the service penetrations should be grouped together and penetrate framed out openings, which are then fire stopped with proprietary systems such as non-combustible batts, board or pillow systems. This approach substantially reduces the risk of fire spread to cavities at a point of weakness and ignition of fires if hot works are being undertaken on the services.

Different approaches may be required for different classes of buildings.

For example:

- Typical office building layouts comprise one or more cores constructed around lift and stair shafts. It is relatively easy to locate facilities such as toilets and kitchens around the core and provide service shafts such that most services are consolidated around the core. Services such as power, communications and air conditioning systems can be distributed easily, since there is very little fire compartmentation required in the office areas.
- Residential buildings differ from offices in that each SOU is a fire compartment and includes bathrooms and kitchens, and therefore in many instances it is impractical to consolidate services such as Drain, Waste & Vent (DWV) pipes around the central core, and service shafts are therefore needed to be distributed around the floor. For apartment buildings, the use of self- contained HVAC systems tends to be preferred; whereas, centralised HVAC systems may be preferred for hotels and more institutional-style buildings, requiring duct penetration of walls and floors to be addressed.

4.9.2 Service Shaft Construction

The requirements for fire-protected timber service shafts used for ventilation, pipes, garbage or similar purpose are summarised in Table 4.14.

Shafts must also be enclosed at the top and the bottom with a floor/ceiling system of the same Fire Resistance Levels and Resistance to the Incipient Spread of Fire Ratings as the walls; except where the top of the shaft is extended beyond the roof, or the bottom of the shaft is laid on the ground.

The shaft is also required to be sound-rated if it passes through more than one SOU and must have a $R_w + C_{tr} \geq 40$ if the adjacent room is habitable and $R_w + C_{tr} \geq 25$ if it is a kitchen or non-habitable room.

Table 4.14: Requirements for fire-protected service shafts in mid-rise timber buildings.

Criteria	Residential Buildings (Class 2 & 3)	Office Buildings Class 5	
		Type A Construction	Type B construction (up to 3 storeys)
FRL loadbearing elements	90/90/90	120/90/90	120/-/-
FRL non-loadbearing elements	-/90/90	-/90/90	-/-/-
RISF (general)	45	45	45
MRISF (massive timber)	30	30	30

In many instances, it is more practical to construct non-loadbearing shafts from laminated board systems or plasterboard/steel stud shaft wall construction in lieu of fire-protected timber construction. If these forms of construction are adopted and the board is non-combustible, then only the FRLs specified in Table 4.14 apply.

4.9.3 Protection of Service Penetrations

Service penetration systems are required by the NCC to comply with AS 4072.1 and AS 1530.4. For services penetrating fire-protected timber elements, there is an added complication in that the cavity temperatures have to satisfy the resistance to the incipient spread of fire or modified resistance to the incipient spread of fire criteria in addition to the integrity and insulation criteria applied to the non-fire side.

Further explanations of the test procedures are provided in Appendix E.

Typical solutions to address resistance to the incipient spread of fire performance criteria include: boxing out openings with plasterboard, filling the area around the service penetration with mineral fibre insulation or transitioning to a different wall type where service penetrations are required.

4.10 Interfacing With Other Forms of Construction

There can be advantages in adopting hybrid forms of construction in buildings. For example, ground floor and basement areas may be constructed from concrete to minimise the risk of water penetration, minimise potential damage in flood-prone areas or address termite management. In addition, this approach allows Classes other than 2, 3 and 5 to be incorporated in mid-rise buildings that are predominately of timber construction, subject to adequate fire separation between the classes.

The relatively low weight of timber structures also makes timber construction ideally suited to the upward extension of existing buildings facilitating infill developments and recycling existing buildings. For example, it may be possible to add apartments above existing retail buildings without having to undertake extensive reinforcement of the foundations.

Refer to NCC Volume One Cl2.8 for further details

Refer to NCC Volume One Cl2.9 for further details

4.10.1 Separation of Different Classes

The NCC addresses the separation of different classifications within a building in Clauses C2.8 and C2.9. For the fire-protected timber concession to apply, it is necessary for Classes other than 2, 3 or 5 to be fire separated from the fire-protected timber construction.

For different classifications on the same storey, the parts having different classifications should be separated by a fire wall having the higher FRL for the two occupancies in accordance with Specification C1.1.

For different classifications in different storeys in a building of Type A construction (most mid-rise buildings), the floor between the adjoining parts must have an FRL not less than that prescribed by Specification C1.1 for the lower storey.

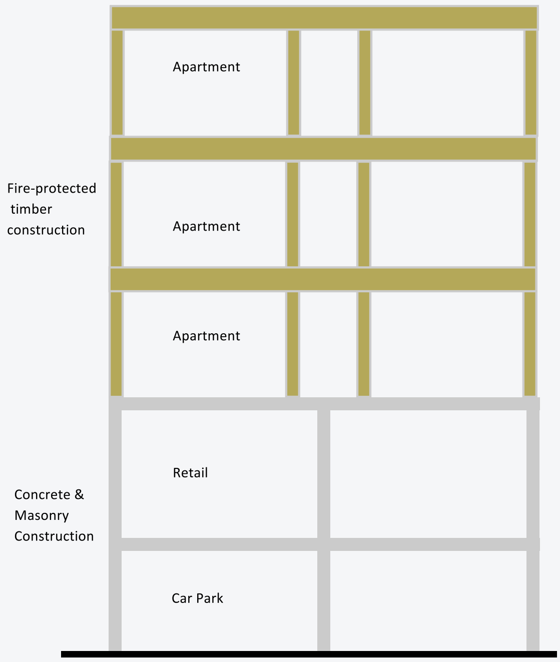


Figure 4.12: Example of multi-class building.

A typical building layout is shown in Figure 4.12 with a retail part of concrete-framed construction below timber-framed apartment levels. For the fire-protected timber concession to apply, the whole building will be sprinkler protected in accordance with NCC Specification 1.1.

Retail use is assigned to Class 6 buildings and therefore from Table 3 of Specification C1.1, the concrete slab separating the retail and apartment levels would require an FRL of 180/180/180. Shafts for lifts, fire stairs and services would be constructed from concrete/masonry on the retail and car park levels, but they may transition to timber-framed construction on the apartment levels. However, in some instances it may be preferred to continue the same form of construction for the entire shaft. Both options are permitted.

4.11 Special Fire Safety Issues

In constructing Class 2, 3 and 5 mid-rise timber buildings, special issues arise as buildings become larger and more complicated. Although this Guide does not attempt to provide information to suit all circumstances, information is provided where there is relevance to timber construction practices.

Refer to NCC Volume One C1.13 for the Fire-protected Timber Concession

4.11.1 Smoke-proof Walls

For Class 2 and 3 buildings, the NCC requires that public corridors greater than 40 m long be divided by smoke-proof walls at intervals of not more than 40 m. These walls must be built from non-combustible materials and extend to the floor above, roof covering or Resistant to the Incipient Spread of Fire ceiling.

Smoke-proof walls can be constructed from fire-protected timber provided the RISF of 45 or MRISF of 30 (for massive timber) is achieved. Where the smoke-proof wall is also required to achieve an FRL (e.g. the wall is loadbearing) the fire-protected wall will also need to meet these FRL requirements.

4.11.2 Bushfire-prone Areas

The requirements for Class 2, 3 and 5 buildings to address the risk of bushfires vary between the States and Territories and may fall under different jurisdictions to standard building works. The need to consider bushfire exposures should be determined early in the design processes by the appropriate authority or authorities and addressed accordingly.

It should be noted that the NCC requires external walls to be of non-combustible in mid-rise buildings and the fire-protected timber concession requires timber elements to be protected by non-combustible fire-protective coverings, providing a good basis for the building to resist bushfire attack at the lower to intermediate BAL levels if adequate protection against ember attack is also provided.

4.11.3 Lightweight Construction Requirements

The NCC requires elements that have a Fire Resistance Level, or that form a lift, stair shaft, an external wall bounding a public corridor, non-fire-isolated stairway or ramp, to comply with Specification C1.8 if they are made out of lightweight materials such as timber framing faced with plasterboard.

Specification C1.8 defines a structural test for lightweight construction, and in most parts is directly related to the performance of the linings used. Appropriate evidence of suitability should be obtained from suppliers of lining material to verify compliance during the design phase.

4.11.4 Robust Structural Design

The 2016 revision of the NCC introduced a verification method for Structural Robustness to facilitate compliance with performance requirement BP1.1(a)(iii).

The verification method states:

Compliance with BP1.1(a)(iii) is verified for structural robustness by:

(a) assessment of the structure such that upon the notional removal in isolation of:

(i) any supporting column; or
(ii) any beam supporting one or more columns; or
(iii) any segment of a load bearing wall of length equal to the height of the wall

the building remains stable and the resulting collapse does not extend further than the immediately adjacent storeys; and

(b) demonstrating that if a supporting structural component is relied upon to carry more than 25% of the total structure a systematic risk assessment of the building is undertaken and critical high risk components are identified and designed to cope with the identified hazard or protective measures chosen to minimise the risk.

The structural design of mid-rise timber buildings should comply with these requirements and the design guidance is provided in WoodSolutions Technical Design Guide #39: *Robustness in Structures* to ensure the building is adequately robust in the event of localised failure of elements during a fire.

4.11.5 FRL Concessions that are Not Applicable to Fire-protected Timber

The fire-protected timber requirements were based on the FRLs prescribed by Specification C1.1 without reductions in FRLs permitted by the following concessions:

- The Residential aged care building concession specified in Cl2.9 of Specification 1.1.
- Vic H103.1 Fire safety in Class 2 and Class 3 buildings should not be applied.

Therefore the above concessions do not apply to mid-rise timber buildings in the 2016 edition of the NCC.

5

Performance Solutions

5.1 Performance Solutions (Alternative Solutions)

The NCC Deemed-to-Satisfy mid-rise timber building solutions introduced in the 2016 edition are intended to provide additional safe and cost effective options. However, due to the generality of the solutions, it may be desirable or necessary to vary these Deemed-to-Satisfy Provisions for a specific building.

The NCC provides this flexibility by allowing a performance pathway (previously referred to as an alternative solution). One of the primary reasons for publishing this Guide was to provide background information on the underlying principles behind the Deemed-to-Satisfy mid-rise timber building requirements to facilitate the development of performance solutions without compromising the fire safety strategy for the building.

The following sections highlight commonly raised options for performance solutions and some of the key issues for consideration. The options and key issues for consideration should not be considered comprehensive and the processes detailed in the NCC and International Fire Engineering Guidelines should be followed when developing performance solutions and preparing Evidence of Suitability.

5.2 Exposed Timber Elements

There are applications where it is preferred that timber structural elements are exposed rather than being protected by non-combustible coverings with the prescribed Resistance to the Incipient Spread of Fire performance. Typical reasons include aesthetics, practicality and cost; although acoustic and thermal insulation requirements may necessitate the use of linings in many instances.

During consultation, some stakeholders raised the issue that the fire severity may be increased as a result of the additional exposed timber, while others argued that the fire would tend to self-extinguish before the timber would be consumed. The behaviour of timber elements will be very sensitive to a number of variables including: the materials and manufacturing process used in the manufacture of the timber element; orientation; exposed surfaces; presence of re-entrant corners; air flow; and background radiant heat flux.

A review of literature reporting full-scale tests demonstrated that exposed timber could contribute to the fire severity although, in the case of ventilation-controlled fires, the fire duration tended to be extended rather than the peak enclosure temperatures increasing. Further details are provided in Appendix A.

Unless specific data is available, a conservative approach is suggested, assuming that all exposed timber elements contribute their total exposed mass to the fire load and that burning timber elements will eventually fail if there is no fire brigade intervention. However, in most cases, subject to careful detailing of timber of larger cross-sections with the required Deemed-to-Satisfy FRLs, fire brigade intervention would be expected prior to collapse if the building layout facilitates access for fire fighters.

5.3 Extended Travel Distance

A common variation sought for Class 2 and 3 Buildings is an extension of the maximum travel distance from an SOU door to a fire-isolated exit from the 6 m maximum specified under the Deemed-to-Satisfy Provisions.

In addition to increasing travel time and potentially compromising way-finding conditions if smoke spreads to the corridor, this variation can also increase the number of SOUs served by a single stair that are at risk from a fire. The analysis should address this issue.

Due mainly to the provision of automatic fire sprinklers, timber mid-rise buildings were shown to present a substantially lower risk to occupants than a non-combustible construction without fire sprinklers.

The methods used for comparison of the timber options can be modified to address extended travel distances and include the effective increase in the SOUs and associated occupants potentially exposed to the fire risk.

5.4 Addition of Combustible Façades

Non-combustible façades can be added to mid-rise timber buildings over the fire-protected timber external walls. See WoodSolutions Technical Design Guide #37: *Mid-rise Timber Buildings*.

However, a performance solution is required to permit combustible façades to be fitted and it should be noted that for composite panels, each layer of the composite must be non-combustible.

Appendix A.6 provides useful background information on the behaviour of timber relating to external fire exposure.

WoodSolutions Technical Design Guide #18: Alternative Solution Fire Compliance, Façades also provides advice on developing performance solutions for timber façades.

In addition, Australian Standard AS 5113 Fire Propagation Testing and Classification of External Walls of Buildings was published in March 2016. The objective of the Standard is to provide procedures for the fire propagation testing and classification of external walls of buildings according to their tendency to limit the spread of fire via the external wall and between adjacent buildings. This may provide a useful option for deriving Evidence of Suitability for combustible external wall systems.

5.5 Effective Height Greater than 25m

It is viable to construct fire-protected buildings above an effective height of 25 m; particularly if massive timber or hybrid construction forms are adopted from a structural perspective.

All buildings above 25 m effective height require automatic fire sprinkler protection in accordance with the NCC Deemed-to-Satisfy Provisions and therefore, if a comparative study is undertaken, the control building would be a sprinkler-protected non-combustible building.

This effectively means that the fire-protected timber needs to provide equivalent or close to equivalent performance to non-combustible fire-resisting construction.

A possible massive timber option would be to increase the performance of fire-protective coverings throughout the building such that ignition of the timber substrate would be unlikely prior to either burnout of the contents or fire brigade intervention, and the large inherent fire resistance of massive timber elements provides an additional redundancy.

Such an approach is described in the publication Mass Timber Buildings of up to 12 storeys[4], which provides details applicable to massive timber buildings up to 40 m (12 storeys high) within the jurisdiction of the Government of Quebec, Canada. Fire-protective coverings (encapsulation) comprising two layers of 16 mm fire-grade plasterboard are required together with fire resistance levels of 120 minutes for loadbearing elements, among other things.

The analysis methods described in this Guide can be applied to evaluate buildings greater than 25 m high, but fire brigade intervention and evacuation times would be substantially increased at heights above 25 m due to issues such as fire-fighter fatigue and access to higher levels.

C

Part C - Fire Engineering Justification

Part C of the Guide provides details of the analysis undertaken to justify the 2016 changes to the NCC relating to mid-rise timber buildings. It is intended to provide a resource to assist in the interpretation of the Deemed-to-Satisfy solutions and to facilitate the development of performance solutions that are consistent with the NCC 2016 mid-rise timber Provisions. A section listing is provided below:

Section	Title
6	Overview of fire engineering analysis
7	Mid-rise buildings chosen for analysis
8	Impact on occupants within SOU of fire origin
9	Impact on occupants outside SOU of fire origin – Non-flashover fires
10	Impact on occupants outside SOU of fire origin – Post-flashover fires
11	Fires in paths of travel
12	Fires in a fire-isolated stair
13	Fires in lift shafts
14	Fires in concealed spaces
15	External fire spread – façade
16	Fire spread between buildings
17	Application of findings to Class 5 buildings

6

Overview of Fire Engineering Analysis

To evaluate the proposed changes to the 2016 edition of the NCC that provide Deemed-to-Satisfy fire-protected timber solutions for mid-rise buildings, it was necessary to determine the change in risk (probability and consequences) of fire spread as a result of an increase in the mass of combustible materials present and response of timber structures to fire compared to the forms of non-combustible construction permitted in the 2015 edition of the NCC.

A preliminary analysis was undertaken and following discussions with stakeholders:

- changes to the NCC were proposed (see Section 4)
- generic buildings layouts including fire protection systems were defined (see Section 7) and occupancy types identified
- fire scenarios and methods of analysis were defined
- key inputs were agreed as appropriate.

Additional analysis assessing the impact of fires on occupants and property within the SOU of fire origin was not required because the preliminary analysis, based on fire incident data, provided a clear indication of a significant improvement in safety for the timber building options from the addition of automatic fire sprinkler systems. Details of the preliminary analysis are provided in Section 8.

The most critical scenario was identified as potential flashover fires occurring within an SOU, since the majority of fires occur within SOUs and the fire load within apartments is relatively high compared to most other locations, and therefore would be expected to provide the greatest challenge to fire-protected timber systems.

A Monte Carlo (multi-scenario) simulation approach was adopted to compare the outcomes relating to the frequency and consequences of potential fully developed fires starting in an SOU (e.g. apartment) on the remainder of the building and structure. The proportion of potential fully developed fires was estimated based on fire spread data from fire incidents and included all fire scenarios where fire spread beyond the enclosure of fire origin was recorded.

Other scenarios were identified that required further analysis. Table 6.1 summarises all the scenarios considered and refers to the relevant sections of this Guide.

Table 6.1: Fire scenarios considered.

Scenario	Sections
Impact of fires on occupants within the SOU of fire origin	**Section 8**
Impact of fires on occupants outside the SOU of fire origin – non-flashover fires	**Section 9**
Impact of fires on occupants outside the SOU of fire origin – post-flashover fires	**Section 10**
Fires in paths of travel to escape routes	**Section 11**
Fires in fire-isolated stairs	**Section 12**
Fires in lift shafts	**Section 13**
Fires in concealed spaces	**Section 14**
External fire spread – building façade	**Section 15**
Fire spread between buildings	**Section 16**

A supplementary analysis was undertaken for Class 5 Office Buildings. The details are provided in Section 15.

7

Mid-Rise Buildings Chosen for Analysis

7.1 Characterisation Principles

To undertake a comparative analysis, it was necessary to define a generic building and to characterise the building and occupants in sufficient detail that parameters relevant to the comparative study could be identified; but without introducing unnecessary complications. For the study, a generic structural and architectural layout was developed that could reasonably be applied to both Class 2 and 3 buildings with minor changes to occupant profiles and fire safety features. A single fire-isolated stair option was considered likely to be more sensitive to variations in the fire safety design and, since a single fire-isolated stair is permitted in buildings with an effective height of not more than 25 m (the upper limit for mid-rise timber buildings in the 2016 NCC Deemed-to-Satisfy solution), this configuration was selected.

It is common for mid-rise Class 2 and 3 buildings to include basement car parks (Class 7) and other occupancies on the ground floor such as office or retail (Class 5 or Class 6). The height of the ground level was increased to address this potential. Parts of the building having a different classification will be fire separated from the Class 2 or 3 parts in accordance with the NCC mid-rise timber building Deemed-to-Satisfy Provisions and have independent egress and access. It was therefore considered unnecessary to define the ground floor layout and basement levels if provided, other than to define discharge points from the fire-isolated exits serving the upper levels and fire protection measures relevant to fire brigade intervention.

7.2 General Building Layout and FRLs

The benchmark (control) was an apartment building with an effective height of 23.1 m (i.e. slightly below 25m) designed in accordance with the NCC Deemed-to-Satisfy requirements specified in the 2015 edition of the NCC. This control was compared to a building designed in accordance with the mid-rise timber building Deemed-to-Satisfy requirements introduced into the 2016 edition of the NCC and described in Section 4 of this Guide.

Figure 7.1 shows a section through the generic Class 2 or Class 3 building and Figure 7.2 shows a schematic plan of a typical residential floor.

As noted above, the ground floor has a greater floor-to-floor height and may contain a different type of occupancy, but independent access and egress will be provided to and from that level and any basements. Therefore only discharge points from the fire-isolated stair serving the upper levels and fire protection measures relevant to fire brigade intervention (including the entry lobby) are shown in the schematic plan of the ground level in Figure 7.1 and Figure 7.3.

The FRLs prescribed by the NCC for elements of construction are summarised in Table 7.1. Symbols are provided to enable the elements to be identified in Figure 7.1 through to Figure 7.3. The FRLs prescribed for elements of construction, that vary with the distance from the boundary (external walls), are summarised in Table 7.2.

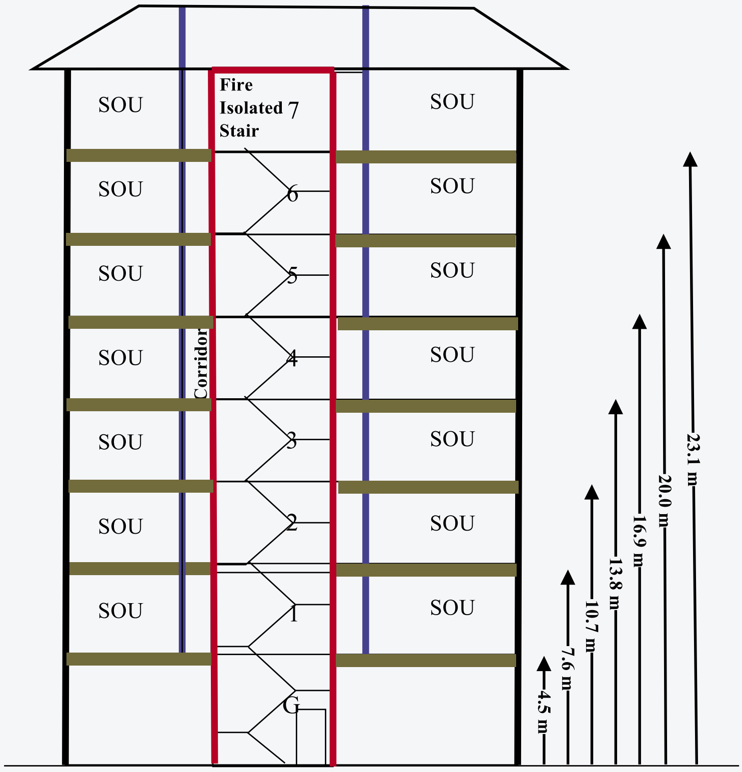


Figure 7.1: Vertical section through generic Class 2/3 building.

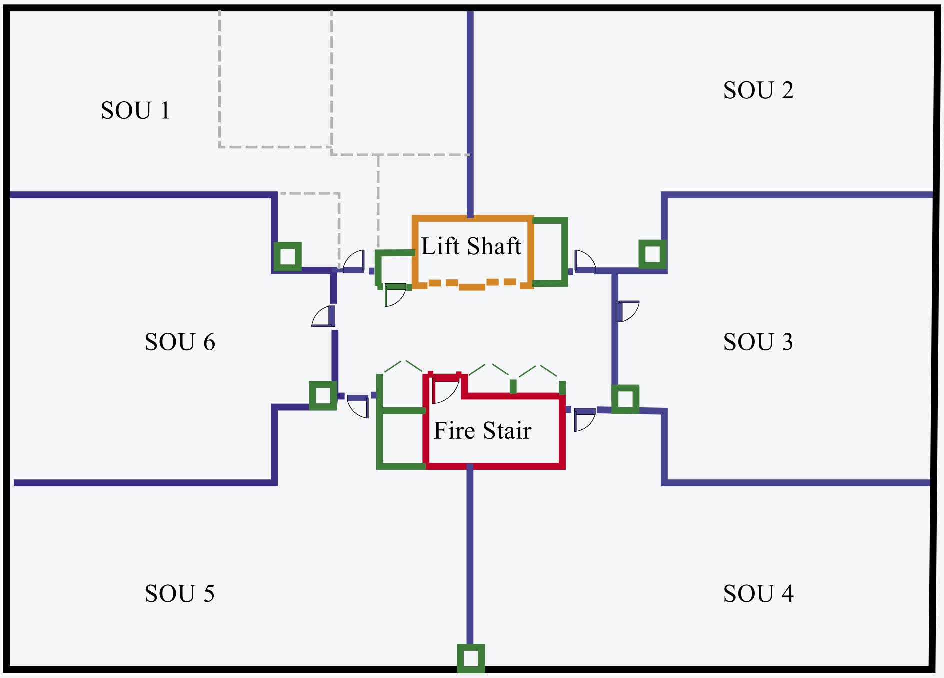


Figure 7.2: Schematic plan of a residential level of a generic Class 2/3 building.

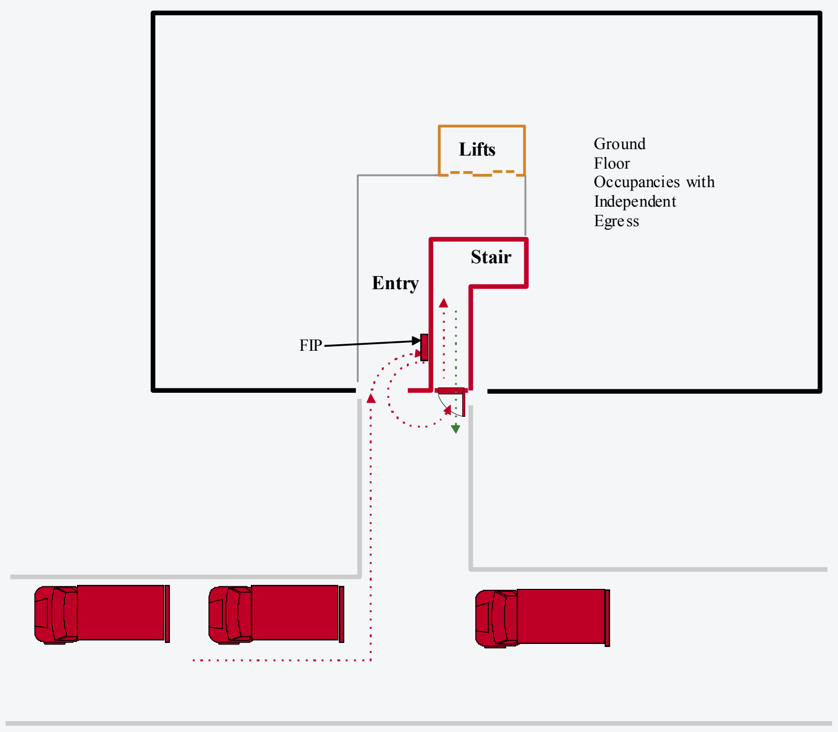


Figure 7.3: Ground floor plan of generic building.

Table 7.1: FRLs for elements of construction – Class 2 and 3 buildings.

Symbol	Description	FRL – Structural Adequacy /Integrity/ Insulation – min		Modified Resistance to the Incipient Spread of Fire (min.)
		Loadbearing	Non-loadbearing	
	Fire stair shaft	90/90/90	-/90/90	30 outside 20 inside
	Service shaft	90/90/90	-/90/90	30
	Bounding Sole Occupancy Units	90/90/90	-/60/60	30
	Lift shaft walls	90/90/90	-/90/90	30
	Door to fire stair	Not applicable	-/60/30	30 outside 20 inside
	Fire door to service shaft	Not applicable	-/60/30	Not applicable
	Door to SOU	Not applicable	-/60/30	Not applicable
	Lift door	Not applicable	-/60/-	Not applicable
	Doors to services risers	Not applicable	-/60/30	Not applicable
	Non-loadbearing walls within an apartment	Not applicable	-/-/-	-
	Floors	90/90/90	Not applicable	30

Table 7.2: FRLs for external walls – Class 2 and 3 buildings.

Symbol	Description	Distance from fire source feature	FRL – Structural Adequacy /Integrity/ Insulation – min	
			Loadbearing	Non-loadbearing
	External walls	<1.5 m	90/90/90	-/90/90
		=15 < 3 m	90/60/90	-/60/60
		= 3 m	90/6030	-/-/-

7.3 Passive Fire Protection Systems

Passive fire protection systems required by the NCC 2015 Deemed-to-Satisfy Provisions are compared to the requirements for mid-rise timber buildings in the 2016 edition in Table 7.3.

Table 7.3: Passive fire protection systems.

System	Deemed-to-Satisfy Provisions for Control Class 2 Steel-Framed Building	Additional/Alternative Measures for Timber Construction
FRLs	Refer Figure 7.1 through Figure 7.3.	No difference
Concrete and masonry construction	Loadbearing internal walls (including shafts and fire walls).	Fire-protected timber in lieu of concrete or masonry
Non-combustible construction	• External walls • Common walls • Flooring and Floor framing to lift pits • Non-loadbearing walls required to be fire-resisting • Non-loadbearing shafts that do not discharge hot products of combustion • Miscellaneous applications	Fire-protected timber in lieu of non-combustible construction
Fire hazard properties	Full compliance with Specification C1.10	No difference
External wall construction, separation distances and openings	Full compliance with Deemed-to-Satisfy Provisions	No difference other than fire-protected timber in lieu of non-combustible construction
Cavity Barriers	No requirements	Required where cavities within fire-resisting structures occur

The steel-frame building with non-loadbearing internal walls was selected for the control building since it is considered to most closely resemble the timber mid-rise buildings. Key elements of construction are summarised in Table 7.4 for the control building and subject buildings

Two subject buildings were required to be compared to the control – a lightweight timber-framed building and a massive timber panel building that used the massive timber provisions which reduces the incipient spread of fire criteria applicable to the general fire-protected timber provisions.

Generally the passive systems are similar for both Class 2 and 3 buildings.

Table 7.4: Passive systems for comparative analysis.

Element	Control Building	Lightweight Timber Frame (Subject Building 1)	Massive Timber (Subject Building 2)
Floor/ceiling assemblies FRL 90/90/90	Concrete slab supported on steel beams. Steel beams protected by sprayed-vermiculite to provide required FRL.	Fire-protected timber floor comprising either solid joists or engineered timber beams spanning between timber-framed walls. Fire-grade plasterboard facings, 2 x 16 mm and timber/mineral fibre cavity barriers (-/45/45) used to protect timber.	Fire-protected cross-laminate timber horizontal panels spanning between CLT walls. Fire-grade plasterboard facings, 1 x 16 mm used to protect timber.
False non-fire rated standard plasterboard ceiling to allow service runs above for all buildings			
Columns / loadbearing walls 90/90/90	Steel columns protected by sprayed vermiculite and clad with non- fire-grade plasterboard.	Fire-protected timber-frame loadbearing walls. Fire-grade plasterboard facings, 2 x 13 mm and timber/mineral fibre cavity barriers (-/45/45) used to protect timber.	Fire-protected cross-laminated timber vertical panels. Fire-grade plasterboard facings 1 x 16 mm.
Non-loadbearing walls	Lightweight steel frame protected by 16 mm fire-grade plasterboard (-/60/60 FRL).	Lightweight timber frame protected by 2 x 13 mm fire-grade plasterboard and timber/ mineral fibre cavity barriers. (Extra plasterboard required to meet incipient spread of fire rating effectively increasing FRL to – /90/90)	Fire-protected cross-laminated timber vertical panels. Fire-grade plasterboard facings 1 x 16mm.
Lift and stair shafts	Structural steel framework with sprayed-on fire protection in combination with non-loadbearing plasterboard shaft wall (-/90/90).	Fire-protected timber-frame loadbearing walls. Fire-grade plasterboard facings, 2 x 13 mm and timber/mineral fibre cavity barriers (-/45/45) used to protect timber.	Fire-protected cross-laminated timber vertical panels. Fire-grade plasterboard facings 1 x 16 mm on outer face of shaft and 1 x 13 mm on interfaces.
Service shafts -/90/90	Solid fire-grade plaster board (multi-layer system).	Solid fire-grade plasterboard (multi-layer system) or fire-grade plasterboard facings, 2 x 13 mm and timber/mineral fibre cavity barriers (-/45/45) used to protect timber if integrated into apartment wall.	Solid fire-grade plasterboard (multi-layer system) or cross-laminated timber protected by a minimum of 16 mm fire-grade plasterboard.
External wall less than 1.5m from fire source feature FRLs 90/90/90 and -/90/90	Structural steel protected by vermiculite. Lightweight steel studs protected by 2 x 13 mm fire-grade plasterboard	Lightweight timber frame protected by 2 x 13 mm fire-grade plasterboard and timber/ mineral fibre cavity barriers.	Fire-protected cross-laminated timber vertical panels. Fire-grade plasterboard facings 2 x 13 mm.
External wall 1.5m to less than 3m from fire source feature FRLs 90/60/60 and -/60/60	Structural steel protected by vermiculite lightweight steel studs protected by 2 x 13 mm fire-grade plasterboard.	Lightweight timber frame protected by 2 x 13 mm fire-grade plasterboard and timber/ mineral fibre cavity barriers.	Fire-protected cross-laminated timber vertical panels. Fire-grade plasterboard facings 1 x 16 mm.
External wall 3m or more from fire source feature FRLs 90/60/30 and -/-/-	Structural steel protected by vermiculite lightweight steel studs protected by 2 x 13 mm fire-grade plasterboard.	Lightweight timber frame protected by 2 x 13 mm fire-grade plasterboard and timber/ mineral fibre cavity barriers.	Fire-protected cross-laminated timber vertical panels. Fire-grade plasterboard facings 1 x 16 mm.
Fire doors -/60/30 modern prototypes with intumescent strips			

7.4 Active Fire Protection Systems

Active fire protection systems required by the NCC Deemed-to-Satisfy provisions are summarised in Table 7.5 for Class 2 buildings.

Table 7.5: Active fire protection systems for Class 2 buildings.

System	Deemed-to-Satisfy Provisions for Control Class 2 Building	Additional/Alternative Measures for Timber Construction
E1.3 Fire hydrants	Internal fire hydrants in accordance with AS 2419.1 provided for each storey	No difference
E1.4 Fire hose reels	Not required for a Class 2 building	No difference
E1.5 Sprinklers	Not provided	System provided in accordance with Specification E1.5 (AS 2118.1/AS 2118.4 as appropriate)
E1.6 Portable fire extinguishers	Provided in accordance with Table E1.6 and AS 2444 as appropriate (impact assumed to be taken into account inherently in estimate of proportion of flashover fires)	No difference (Impact assumed to be taken into account inherently in estimate of proportion of flashover fires)
E1.8 Fire control centre	Not required since building less than 25m effective height	No difference
E2.2 Smoke hazard management **Fire detection/alarm system in accordance with Spec 2.2a. Independent exit from parts of other classes therefore no stair pressurisation required**	Self-contained smoke alarms in SOUs Smoke alarms or detectors in public corridors and other internal public spaces activating a general building alarm	No difference – Self-contained smoke alarms in SOUs Activation of any sprinkler will raise alarm throughout the building.
E2.2 System monitoring	None	Fire sprinkler system monitored with automatic notification of fire brigade

Active fire protection systems required by the NCC Deemed-to-Satisfy Provisions are summarised in Table 7.6 for Class 3 buildings. These are generally similar to those for Class 2 buildings, except for enhancements to the requirements for detection and alarm and monitoring requirements under E2.2 of the NCC.

Table 7.6: Active fire protection systems for Class 3 buildings.

System	Deemed-to-Satisfy Provisions for Control Class 3 Building	Additional/Alternative Measures for Timber Construction
E1.3 Fire hydrants	Internal fire hydrants in accordance with AS 2419.1 provided for each storey	No difference
E1.4 Fire hose reels	Not required for a Class 3 building	No difference
E1.5 Sprinklers	Not provided	System provided in accordance with Specification E1.5 (AS 2118.1/AS 2118.4 as appropriate)
E1.6 Portable fire extinguishers	Provided in accordance with Table E1.6 and AS 2444 as appropriate (Impact assumed to be taken into account inherently in estimate of proportion of flashover fires)	No difference (Impact assumed to be taken into account inherently in estimate of proportion of flashover fires)
E1.8 Fire control centre	Not required since building less than 25 m effective height	No Difference
E2.2 Smoke hazard management **Fire detection / alarm system in accordance with Spec 2.2a. Independent exit from parts of other classes therefore no stair pressurisation required**	Building wide smoke detection system generally in accordance with AS 1670.1 Activation of any smoke or heat detector will raise alarm throughout the building.	No difference to detection system except sprinkler heads can provide coverage in areas prone to false alarms in lieu of heat detectors. Activation of any sprinkler or smoke detector will raise alarm throughout the building.
E2.2 System monitoring	Smoke detection system is monitored with automatic notification to fire brigade	Fire sprinkler system and smoke detection system monitored with automatic notification of fire brigade

7.5 Occupant Characteristics

The occupant characteristics will be identical for the timber (subject) buildings and control (Deemed-to-Satisfy Provisions).

However, the occupant characteristics may vary between Class 2 and the various sub-categories within Class 3 buildings. The definitions for Class 2 and Class 3 buildings from the BCC are summarised below:

Class 2: a building containing 2 or more *sole-occupancy units* each being a separate dwelling.

Class 3: a residential building, other than a building of Class 1 or 2, which is a common place of long term or transient living for a number of unrelated persons, including -

(a) a boarding house, guest house, hostel, lodging house or backpackers accommodation; or
(b) a residential part of a hotel or motel; or
(c) a residential part of a school; or
(d) accommodation for the aged, children or people with disabilities; or
(e) a residential part of a health-care building which accommodates members of staff; or
(f) a residential part of a detention centre.

The occupant characteristics of Class 2 buildings can be considered to be broadly representative of the Australian community and this profile was also applied to Class 3(a), (b), (c), (e) and (f) occupancies which were defined as Type 1 occupants.

Class 3(d) occupancies accommodate larger proportions of people who will require assistance to evacuate and hence present a greater fire risk and were defined as Type 2 occupants. In these instances, some level of staff assistance would be required to facilitate evacuation, which may vary from simply providing direction to providing physical assistance to occupant(s) who may or may not be aware of the emergency.

These two Types were considered to bracket other Class 3 occupants.

7.6 Emergency Exit Provisions

Emergency exit provisions are in accordance with the NCC Deemed-to-Satisfy provisions and were the same for the subject buildings and control. They are shown schematically in Figure 7.1 through Figure 7.3.

8

Impact on Occupants within the SOU of Fire Origin

8.1 General Fire Safety Provisions within a SOU

Under the Deemed-to-Satisfy Provisions of the NCC, each apartment (SOU) has fire-resisting bounding construction forming a fire compartment but there is no requirement for further fire compartmentation within the SOU. For Class 2 buildings, the apartment is normally provided with stand-alone fire alarms, similar in function and location to a typical family dwelling, raising an alarm within the SOU of fire origin only. For Class 3 buildings, a general building alarm system is provided.

It is reasonable to assume that after flashover the probability of any remaining occupants within the SOU of fire origin surviving for a significant period is low.

The following sections consider the two critical variations:

- Where non-combustible construction and masonry or concrete construction is specified in the Deemed-to-Satisfy Provisions of the NCC, fire-protected timber will be used.
- The addition of automatic fire sprinklers in buildings with an effective height of not more than 25 m.

8.2 Fire-protected Timber instead of Non-combustible or Masonry or Concrete Construction for the Walls Bounding an SOU

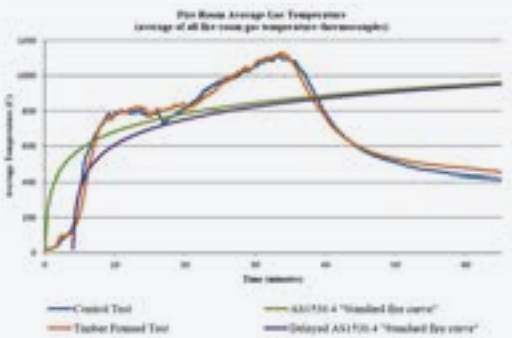
Under the proposed changes, the timber structural members forming the bounding walls of a fire compartment will be protected with non-combustible materials capable of preventing the interface with the timber exceeding 300°C (onset of charring) for massive timber panels, and 250°C for lightweight timber frame construction, for a considerable period – facilitating fire brigade intervention before ignition of the timber substrate. This limit will be exceeded substantially after untenable conditions occur within the SOU of fire origin, and therefore the outcomes would be expected to be similar for the existing Deemed-to-Satisfy Provisions and the use of fire-protected timber for the bounding walls, if the substantial impact of the additional automatic fire sprinkler system is ignored.

This was demonstrated in comparative full-scale fire tests with room enclosures lined with fire-grade plasterboard. One enclosure was of lightweight steel construction (the non-combustible control test) and the other was of lightweight timber-framed construction (timber-framed test). Timber cribs were used as the fire load and an insulated column included in the enclosure to compare the fire severity, as shown in Figure 8.1. Typical results are presented in Figure 8.2 and show that there was no increase in fire severity based on a range of parameters including enclosure temperature, heating rate of an insulated steel column, non-fire side temperatures of the enclosure partitions or cavity temperatures. See England and Eyre[5] for further details.

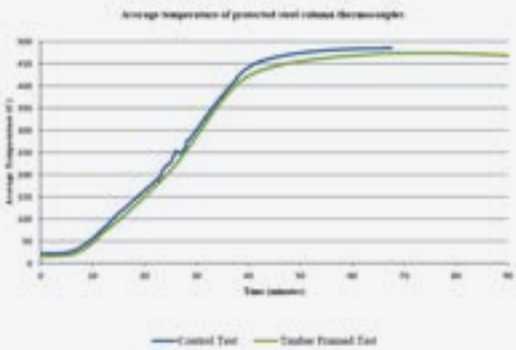
Timber cribs and insulated column before testing

Enclosures during fully developed fire tests

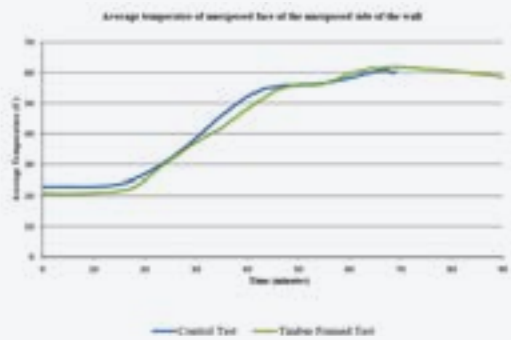
Figure 8.1: Comparative testing of non-combustible and timber-framed construction.



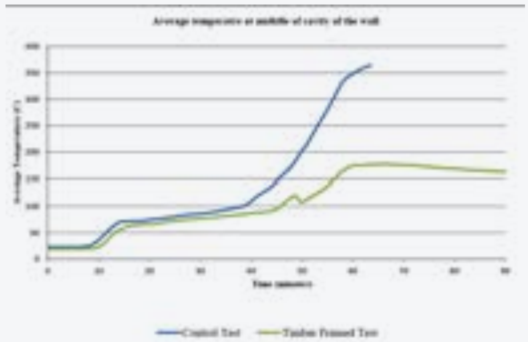
Average Enclosure Temperatures



Average temperature of Protected Steel Beam



Average Unexposed Face Temperatures of Partitions



Average temperature in Centre of Cavity of walls

Figure 8.2: Results of comparative testing of non-combustible and timber-framed construction.

8.3 Additional Provision of an Automatic Fire Sprinkler System

When a fire sprinkler operates successfully, the fire will be suppressed or controlled prior to flashover, greatly enhancing the safety of occupants within the apartment of fire origin.

Due to the relatively small population size and small proportion of residential buildings with automatic fire sprinkler systems in Australia, there is insufficient Australian statistical data to reliably establish the impact of the addition of automatic fire sprinklers to residential buildings. It is therefore reasonable to use data from the US, where the larger population and greater proportion of residential buildings with automatic fire sprinkler protection provides a much larger sample.

A detailed study of the "U.S. Experience with Sprinklers" based predominately on US fire statistics for the period 2006–2010 was undertaken by Hall, 2012[6]. Relevant key findings and data from the report are summarised below:

- Sprinkler systems were present in 22,270 home-reported fires (including apartments) – 6% of all reported home fires.
- The estimated number of home fires large enough to be capable of activating a sprinkler head was 2,520 (11% of reported fires in sprinkler protected homes).
- Percentage of home fires where sprinkler system operated effectively – 92%
- Percentage of all structure fires where sprinkler system operated effectively – 88%
- Percentage of home fires confined to room of origin – 55% without sprinklers, 88% with sprinklers
- Home fire fatalities/1000 reported fires – 7.3 without sprinklers, 1.3 with wet pipe sprinklers (i.e. 83% reduction)
- Average direct property damage/home fire – US$20,000 without sprinklers, US$6,000 with wet pipe sprinkler system (i.e. 69%) reduction.

The report also estimated that the number of false discharges (due to accidental impacts, for example) from fire sprinklers in homes was about 5% of fire incidents where sprinklers operated. This estimate was based on smaller sample sizes using data from 2003–2006.

8.4 Impact of Proposed Changes within an SOU of Fire Origin

On the basis of the above discussion and the analysis included in Appendix F, it was concluded that the net impact of the proposed changes to the NCC compared to existing Deemed-to-Satisfy provisions on the occupants within the SOU of fire origin would be a substantial reduction in fatalities and direct property damage. Due to the magnitude of these changes and the substantial data available that demonstrates the improvement in safety resulting from the introduction of automatic fire sprinkler systems, it was considered unnecessary to undertake further analysis with respect to the risk to occupants within the SOU of fire origin.

9 Impact on Occupants Outside the SOU of Fire Origin – Non-flashover Fires

9.1 Small Flaming and Smouldering Fires

Small flaming fires and smouldering fires of insufficient size to activate a sprinkler head would be unlikely to penetrate the non-combustible insulating layer applied to fire-protected timber and cause ignition of the timber. Therefore no significant difference in outcome would be expected between the subject fire-protected timber buildings and control building meeting NCC 2015 Deemed-to-Satisfy Provisions based on non-combustible construction.

No further analysis of these scenarios was considered necessary and the Deemed-to-Satisfy fire-protected timber solutions within the NCC 2016 and the NCC 2015 Deemed-to-Satisfy solutions described in Section 4 were considered to be equivalent for small flaming and smouldering fires.

Cavity fires have been considered separately in Section 14.

9.2 Large Flaming Non-Flashover Fires

These fires would be of sufficient size to activate an operational fire sprinkler system. If the fire sprinkler system operates effectively, the fire size would be limited or suppressed for the fire-protected timber options and, in addition, a general building alarm would be raised and automatic fire brigade alert would be activated.

In the low probability of sprinkler failure, the timber core would be protected from large flaming non-flashover fires by the fire-protective coverings. Since fire-protected timber is designed to provide protection against fully developed fires, it is considered unlikely that the fire would be of sufficient size to cause ignition of timber, and no significant difference in outcome would be expected between the subject timber building solutions and the control building complying with NCC 2015 Deemed-to-Satisfy Provisions if the sprinkler system failed to operate effectively.

For a large proportion of scenarios, the door to the SOU would be closed, minimising smoke spread to escape routes.

In the low probability event that the door to the SOU or compartment of fire origin was open, smoke spread would be similar for the solutions being considered if the sprinkler system failed to operate; as would the outcomes, as the detection and alarm systems and occupant profiles would be similar. However, in the majority of scenarios where the sprinkler system operates, it would be expected that the risk to life would be significantly less for the sprinkler-protected option.

It was therefore considered that no further analysis of these scenarios was required, and that the NCC 2016 timber solutions would be expected to provide a reduction in the expected risk to life of occupants outside the SOU of fire origin compared to the NCC 2015 Deemed-to-Satisfy Provisions identified in Section 4 for large flaming non-flashover fire scenarios.

10 Impact on Occupants Outside the SOU of Fire Origin – Post-flashover Fires

Fully developed (post-flashover) fires have the greatest potential to challenge the fire-protected timber, and therefore a more detailed multi-scenario quantitative risk assessment was considered necessary. The adopted approach used the EFT Multi-scenario Quantitative Risk Assessment Framework.

10.1 EFT Multi-scenario Quantitative Risk Assessment Framework

The EFT Multi-scenario Quantitative Risk Assessment Framework was developed for the analysis of fully developed fires in multi-storey structures. Details of the framework have been described by England[7] and are described further in this Section. A key feature of the framework is the ability to undertake multi-scenario analyses taking into account the time dependency of factors, such as:

- response of elements of construction to fire incorporating the variability of FRLs and effects of installation faults
- smoke spread
- detection and alarm system activation
- fire brigade intervention
- occupant response.

This removes a major limitation with earlier multi-scenario analysis models and simple event tree analyses, which were unable to consider time dependencies when analysing the impact of changes that effect parameters such as fire brigade intervention, FRLs of elements of construction and occupant response – particularly beyond the floor of fire origin.

The framework comprises three core models and three input models as shown in Figure 10.1. The risk of structural collapse and/or the number of occupants exposed to untenable conditions are the primary outputs, enabling individual and societal risks to be estimated for occupants within the building together with the risk of structural collapse. A major structural collapse could affect people and property outside the building of fire origin and, in many instances, could be an important parameter for comparison of fire safety strategies.

The core models comprise:

- enclosure fire/structural
- fire brigade intervention
- occupant response evacuation and consolidation.

The input models comprise

- sprinkler intervention
- base smoke spread
- detection and alarm.

These core models and input models use various sub-models that can be selected to suit the particular applications, providing the flexibility to allow different sub-models to be incorporated into the framework if they are more suited to a particular application.

The sub-models used in conjunction with the framework to evaluate the mid-rise timber building Provisions included in the 2016 edition of the NCC are described in this Section, together with the adopted inputs. Further information on the models and derivation of inputs is provided in Appendices F and G.

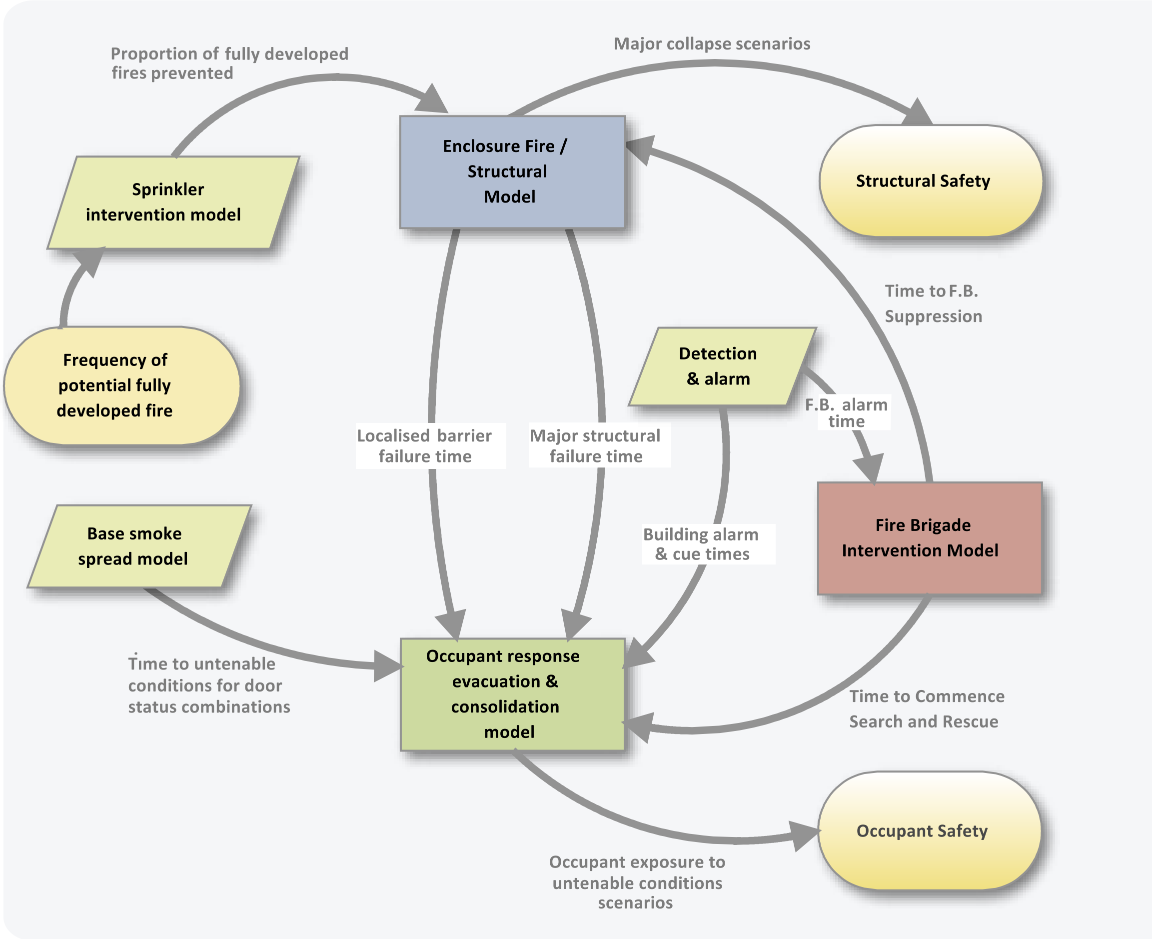


Figure 10.1: EFT Multi-scenario quantitative risk assessment framework.

10.2 Frequency of Potential Fully Developed Fires

The Report on Government Services 2013[8] included a report on accidental residential fires reported to fire services from 2008 to 2012 from which it can be estimated that there are approximately 100 fires reported per 100,000 households per annum, i.e. 10^{-3} fires /household per annum are reported. This is expected to provide a reasonable indication of fire starts in apartments.

The proportion of potential flashover fires was reported in Apte et al.[9] , based on the work of Yung, Benichou, Narrayanan and Whiting. The resulting estimates are summarised in Table 10.1, with unknown fires sizes in the NZ data proportionally distributed.

Table 10.1: Proportions of flashover fires.

Fire type	Australia	US	Canada	NZ
Smouldering fire	24.5%	18.7%	19.1%	27.0%
Non-flashover fire	60.0%	63.0%	62.6%	49.8%
Flashover fire	15.5%	18.3%	18.3%	23.2%

Since most households are single dwellings, it is reasonable to assume that few of these fires occurred in sprinkler-protected buildings, and therefore it is estimated that approximately 18% of fires would progress to flashover if no automatic fire sprinklers were present.

Therefore 1.8×10^{-4} potential flashover fires/household/annum are estimated to occur.

An approximation of the frequency of flashover fires in an apartment block can be obtained by using the following equation:

Frequency of potential flashover fires = 1.8×10^{-4}/apartments/annum in the building.

This is potentially a conservative (overestimate of frequency), since it may contain some larger fires that did not reach flashover. However, since the analysis being undertaken is predominately a comparative analysis, this approximation was considered reasonable.

10.3 Sprinkler Intervention Model

For the purposes of the analysis of potentially fully developed fires, it was considered adequate to adopt a simple intervention model based on an analysis of fire data assuming that if the sprinkler operated in accordance with its design objectives it would either control the fire or suppress the fire, preventing transition to a fully developed fire.

Due to the relatively small population size and small proportion of residential buildings with automatic fire sprinkler systems present in Australia, there is insufficient Australian statistical data to reliably establish the impact of the addition of automatic fire sprinklers to residential buildings. It is therefore reasonable to use data from the US, where the larger population and greater proportion of residential buildings with automatic fire sprinkler protection provides a much larger sample.

A detailed study based predominately on US fire statistics for the period 2006–2010, *U.S. Experience with Sprinklers*, was undertaken by Hall, 2012[6]. Relevant key findings and data from the report are summarised below:

- percentage of home fires where sprinkler system operated effectively – 92%
- percentage of all structure fires were sprinkler system operated effectively – 88%.

Further confidence in the applicability of the above data to Australian buildings can be obtained by comparing the above statistics with other studies.

A detailed summary of available sprinkler system component data and reports on the effectiveness for fire sprinkler systems was undertaken by Frank et al.[10]. It found that estimates of effectiveness varied from 70% to 99.5%, depending to a large extent on definitions and selection of data. For probabilistic analysis, it was suggested that a distribution be considered with a peak between 90% and 95%.

Moinuddin, Thomas and Chea[11] estimated failure rates between 3% and 14% for office buildings in Australia, but indicated that by fitting isolation valves on each storey the reliability could be improved by 13%.

Koffe[12] published a paper analysing US sprinkler reliability data from the NFPA, and proposed a reliability of 90%.

A study by BRANZ estimated the reliability of domestic sprinkler systems to be about 95%; however, this study assumed 99.9% reliabilities for operation of the sprinkler head, effectiveness of the sprinkler discharge, design competence and correctness of installation. It also assumed 99% reliability for the operational valves, but this is substantially higher than the estimates of Moinuddin, Thomas and Chea.

A reliability of 92% was adopted for the detailed study, which is consistent with the estimate from the Hall study.

If the sprinkler system operated successfully, it was assumed that the consequences of a fire occurring within an SOU – with respect to the risk to life of occupants – would be limited to the SOU of fire origin and that fire-resisting elements of construction would not fail.

Reference should be made to Section 8 for estimation of the consequences of fires within the SOU of fire origin.

10.4 Base Smoke Spread Model

Prior to failure of fire-resisting elements of construction, smoke spread can occur through various leakage paths but will tend to be dominated by the state of doors such as the door to the apartment of fire origin. If exit paths become smoke logged, it will affect the ability of occupants to self-evacuate and also the speed (and efficacy) with which the fire brigade can undertake search and rescue and suppression activities. Prior to failure of elements of construction, the conditions will be the same for all strategies for scenarios where there is no automatic fire suppression.

The base smoke spread model determines the conditions in various enclosures assuming there are no fire-induced failures of barriers (i.e. smoke spread occurs through existing openings only). The open/closed status of doors is considered and smoke spread is modelled for various combinations of openings states. Experiments on fire doors were used to estimate the performance of doors in the closed state.

Inputs to the occupant response evacuation and consolidation model are:

- the probabilities of the doors being closed during the fire
- the times to low visibility for various combinations of door open states
- the times to untenable conditions in enclosures outside the SOU of fire origin for various combinations of door open states.

10.4.1 Probability of Doors being Open at the Time of a Fire

A report on the fire system effectiveness in major buildings in New Zealand[13] included inspection data from university, hospital, and office/retail buildings relating to more than 5,000 passive fire protection systems, including fire doors. The results shown in Table 10.2 have been extracted from the NZ Study.

Table 10.2: NZ fire and smoke door survey results.

Issue	Fire Doors (%)	Smoke Doors (%)	Riser Hatches (%)
Wedged/blocked	1.9	1.8	
Painted smoke seals	0.5	0	
Missing smoke seals	4.8	10.3	
Excessive clearance	0	1.8	2.5
Carpet under door	1.4		
Excessive force to open	0.5		
Missing closers	1.5	1.5	
Damaged closers	0	0	
Not fully closing	2.9	2.9	
Total	**13.5**	**18.3**	**2.5**

These results are incorporated in Table 10.3, which also includes data provided from other sources including Moinuddin and Thomas[14] and England et al.[15].

Of the 34% of doors with faults in the Kettle study, only 4.5% could not be closed by manual means. It should be noted that regular maintenance/inspection as required in most States and Territories in Australia would have been likely to improve the performance considerably.

The mean of the above results is approximately 80%.

In modern air conditioned apartment buildings, SOU doors would normally be in the closed state, so issues such as chocking doors open would be less likely to occur and the doors would be capable of being closed for security reasons. The self-closing function is, however, important to address, as closing the door may be overlooked during emergency evacuation.

Table 10.3: Summary of fire door survey results.

Source	Estimated-Reliability
Guymer and Parry – US Nuclear Industry 1970-80 data	92.6%
BS DD240 – General fire doors	70%
BS DD240 Self-closing door to protected stairwell	90%
Moinuddin and Thomas, Australia – survey of 16 buildings	79%
Moinuddin and Thomas, Australia – smoke door estimate from 6 buildings	>65%
FM study of 1183 swinging fire doors	86%
NZ study – Fire doors	86%
NZ study – Smoke doors	82%
Kettle UK Study – Single doors	66%

It was therefore considered reasonable to assume that the probability of the door to the SOU of fire origin being closed would be 0.9. The same value was adopted for the fire-isolated stair doors and doors/panels providing access to service shafts. Other SOU doors were assumed to have a probability of being closed of 0.95, since the initial state is likely to be closed and therefore they are not as reliant on a self-closing function. The same values are applicable to both the subject and control buildings and are summarised in Table 10.4.

Table 10.4: Probabilities of fire doors being closed.

Door	Probability of Door Closed
SOU of fire origin	0.9
Other SOUs	0.95
Fire stair doors	0.9
All other fire doors	0.9

10.4.2 Visibility and Tenability Criteria

The study is comparative and, because of the large number of variables considered (including human behaviour), it was considered appropriate to adopt the following relatively crude indicative visibility and tenability criteria:

- A temperature rise of 10°C approximates to poor visibility (occupants are assumed not to evacuate through this level of smoke and fire brigade activities will be slower).
- A temperature rise of 60°C will be assumed to represent untenable conditions for occupants. The interface between the upper and lower layers outside the apartment of fire origin was sufficiently low to assume occupants would be exposed to the upper layer temperatures. This limit is below the short term exposure tenability criteria for temperature suggested by Engineers Australia Society of Fire Safety[16] and will inherently address a 2.5kW/m^2 radiant heat flux tenability limit.
- The fire brigade intervention model[17] nominates a limiting heat flux of 4.5kW/m^2 for search and rescue activities. The Society of Fire Safety Practice Note includes refined limits for Fire Brigade Intervention which are reproduced in Table 10.5, together with the classifications adopted in this study.

Table 10.5: Tenability criteria for fire brigade intervention.

Criteria	Routine Condition	Hazardous Condition	Extreme Condition	Critical Condition
Max Time – min	25	10	1	<1
Max Air Temp – °C	100	120	160	>235
Max Radiation (kW/m^2)	1	3	4-5	>10
Grouping for this project	Reasonable		Challenging	

10.4.3 Performance of Closed Fire Doors

There are two broad categories of fire door currently supplied in Australia. One category is based on prototypes tested since the introduction of the cotton pad test to the standard fire resistance test, to determine performance under the criterion of integrity (modern prototypes). The other is based on prototypes tested prior to the introduction of the cotton pad (old prototypes).

The main difference is that the modern prototypes tend to incorporate intumescent strips to retard the spread of hot gases around the perimeter of the door.

The difference in performance of doors with and without intumescent seals was documented by Young and England[18]. The doors were subjected to the AS 1530.4 Standard heating regime and an instrumented corridor was placed in front of the door. For the door without seals, approximately 100% smoke obscuration coincident with a hot layer temperate increase of approximately 30K was measured in the corridor within 2 minutes of the introduction of a positive pressure differential across the door (i.e. the pressure is higher on the fire [furnace] side than the corridor and increases with height due to the buoyancy of the hot gases). For the door with intumescent seals, 100% of smoke obscuration was measured about 15 minutes after the introduction of a positive pressure, coincident with an approximate 30K temperature rise.

The analysis assumes modern prototype doors with intumescent seals are provided, but it should be noted that old prototypes are still deemed to comply within the NCC. The performance of old prototypes will be bracketed between the door open and door closed conditions.

Full-scale enclosure tests were undertaken to compare the performance of non-combustible construction and timber-framed construction in 2011[15]. These tests also incorporated a corridor at the rear of the enclosure separated by the bounding partition and a fire door. Additional data relating to the door/corridor test is reported separately[19]. The doors were modern prototype -/60/30 fire doors fitted with intumescent seals. Typical temperatures measured in the corridor by four trees are shown in Figure 10.2.

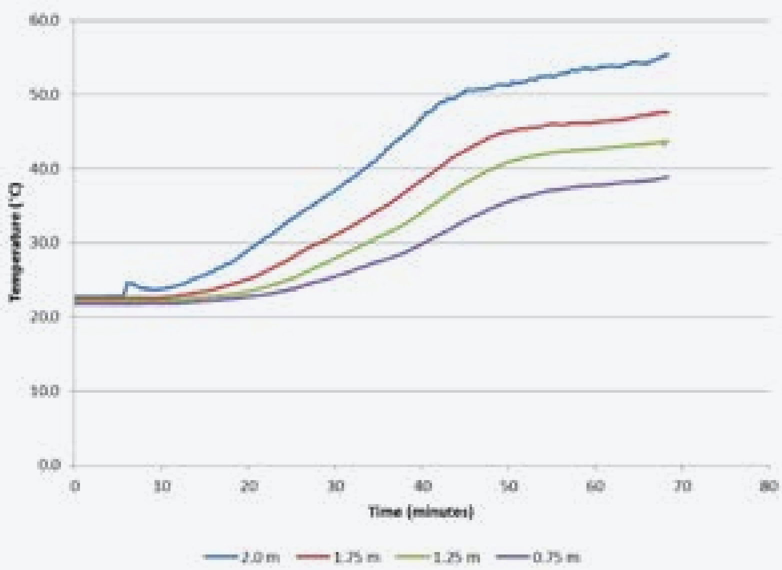


Figure 10.2: Corridor temperatures from comparative natural fire tests (fire doors fitted with intumescent seals).

The mean temperature at a height of 1.75 m did not exceed a 30K rise for 66 minutes when the control test was terminated, and exceeded 30K after about 80 minutes during the timber-framed room test. While this temperature rise correlates with zero visibility (see above) the fire brigade would be able to operate at these modest rises in temperature. It is therefore considered reasonable to assume that the fire brigade would be able to operate safely within the corridor if the door to the apartment of fire origin is closed until failure of the fire doors.

Reasonable levels of visibility will be assumed to be maintained for a scenario time of 30 minutes based on a temperature rise of about 10°C at a height of 1.75 m within the corridors (see Figure 10.2). Until this temperature is exceeded it will be assumed that occupants are capable of navigating the corridor and that fire brigade operations are not hindered by smoke production. Beyond this limit it will be assumed that occupants cannot evacuate through the smoke unassisted.

On the same basis, old prototype doors would be expected to maintain tenable conditions in the corridor for about 2 minutes after flashover but, as noted above, it is assumed modern prototype doors will be used. The use of modern prototype doors will reduce the advantages of the provision of an automatic fire sprinkler system and therefore will yield conservative results in the context of this assessment (lesser performance for timber construction).

As the fire door will tend to have lesser or similar performance than the corridor wall, the combined corridor wall/door performance with respect to fire and smoke spread will be based on the door performance.

10.4.4 Smoke Modelling

To provide approximate estimates of the extent of smoke spread, typical scenarios were modelled using the CFAST Version 6[20]. It was assumed that the fire floor was two levels from the top of the building and, where appropriate, smoke spread via the shafts was modelled to the upper level corridor and subsequently to an upper level of apartments. For the door open scenario, the door to the apartment of fire origin was opened after 3 minutes, which approximated to flashover, simulating a last minute evacuation and failure of the automatic door closing device that is required to be fitted to the door in accordance with the NCC Deemed-to-Satisfy Provisions.

Smoke spread estimates through closed doors were based on the experimental data described in Section 10.4.3. Table 10.6 summarises the results for baseline critical times obtained for various enclosures.

Table 10.6: Baseline critical times for visibility and tenability.

Time to Exceed Limits – min			
Fire Floor Corridor Visibility	**Fire Floor Non-Fire (NF) SOU Tenability**	**Stair Visibility**	**Upper Level SOU Tenability**
SOU Fire Origin Door Open – Visibility 0.5	NF SOU Door Open Tenability 1	Stair Door Open Visibility more than 2.5	SOU Door Open Tenability more than 120
	NF SOU Door Closed Tenability more than 60	Stair Door Closed Visibility more than 10	SOU door Closed Tenability more than 120
SOU Fire Origin Door Closed – Visibility 30	NF SOU Door Open Tenability more than 60	Stair Door Open Visibility more than 60	SOU Door open Tenability more than 12
	SOU Door Closed Tenability 120	Stair Door Closed Visibility more than 69	SOU door closed Tenability more than 120

Fire Brigade conditions were considered reasonable for all areas except on the floor of fire origin if the SOU of fire origin door is open or has failed, in which case the conditions were considered challenging. Since the study was comparative and the base smoke spread would be the same for all the generic buildings, it was considered unnecessary to undertake more detailed smoke modelling.

10.5 Detection and Alarm Model

10.5.1 Overview of Derivation of Inputs

Since the focus of the detailed analysis was fully developed fires, the treatment of the pre-flashover phase and determination of alarm times could therefore be relatively simple, provided reasonable estimates of the fire brigade alarm times and commencement of evacuation could be made relative to the occurrence of flashover.

Large variations in the rate of initial fire growth and detection and alarm times occur with the impact of human behaviour, further increasing the variability particularly in occupancies such as Class 2, where emergency management structures are limited. To address this variability, probabilistic distributions of alarm and response times were derived and used in the analysis, rather than allocating a specific time to an event.

The alarm time for occupants was consolidated into the occupant response and evacuation model for the purposes of this study to allow for reinforcement from secondary cues. Reference should be made to Section 10.8.

The derivation of the distributions for fire brigade alarm times relative to the start of the parametric heating regime (rapid growth phase) is detailed in Section 10.5.2 and Section 10.5.3.

Rectangular alarm time distributions were assumed for the fire brigade intervention model as shown in Figure 10.3 and Table 10.7. The inputs vary between Class 2 and some Class 3 buildings, due to the presence of monitored detection/alarm systems.

Table 10.7: Fire brigade alarm time distributions.

Fire Detection/Alarm System Monitoring Status	Time relative to start of parametric heating regime	
	Minimum – minutes	**Maximum – minutes**
Not monitored	0	4
Monitored	-10	2

In the majority of scenarios, the transition to a fully developed fire (flashover) occurs within two minutes of the start of the parametric heating regime, if it is assumed an enclosure temperature of 600°C corresponds to flashover.

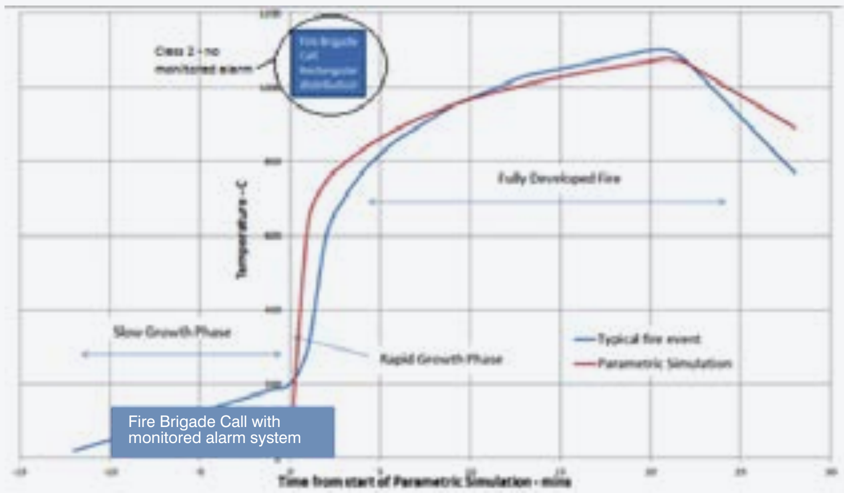


Figure 10.3: Distributions for fire brigade alarm times

10.5.2 Derivation of Class 2 Fire Brigade Alarm

The control Deemed-to-Satisfy Class 2 building did not have a direct connection to a monitoring service and therefore fire brigade notification depended on a call from an occupant or member of the general public.

While the subject timber buildings were provided with automatic fire sprinkler systems connected to a monitoring service, the sprinkler systems would be likely to have failed if a flashover fire occurred. In many instances, if the sprinkler system fails to control a fire due to isolation of part or all of the system, it is likely that the sprinkler system would not initiate an alarm. Therefore, for the purposes of considering fire brigade intervention for fully developed fire scenarios, it was assumed that the fire brigade would be alerted by means of a call from an occupant or member of the general public.

Considering a typical fire scenario after ignition, in many instances there is a slow growth phase (sometimes referred to as the incipient phase) while the fire becomes established. This is followed by more rapid growth, often simulated by a t-squared fire, until flashover – when the fire transitions to a fully developed fire, as shown in Figure 10.3.

The fire brigade could be alerted at any stage after ignition depending upon (among other things):

- the presence of occupants in close proximity to the fire (e.g. within the SOU of fire origin)
- the status of the occupants close to the fire
- response to alarms and fire cues
- the perception of risk associated with the fire.

As the fire approaches flashover, the cues would become stronger and evident to other occupants and passers-by, significantly increasing the probability of an emergency call being made.

Due to the variability of the fire during the establishment phase and the variability of human behaviour, it was conservatively assumed that no alarm calls would be made during this stage and a rectangular distribution of alarm calls over a four-minute period from the start of the parametric simulation was assumed. During this period, large numbers of occupants, as well as potential passers-by, could receive clear unambiguous cues such as flames exiting windows, glass breaking, or large volumes of smoke being produced, and therefore the probability of at least one person making a call to the fire brigade would be high.

10.5.3 Derivation of Class 3 Fire Brigade Alarm

For Class 3 buildings, the detection and alarm system is required to be monitored and therefore if the detection and alarm system operates successfully the fire brigade will be alerted prior to flashover. How much earlier depends on a large range of variables. In extreme circumstances, flashover could occur within 2–3 minutes of the alarm or it could take several hours.

A rectangular distribution commencing 10 minutes prior to the parametric heating curve and ending two minutes after the start of the parametric curve was adopted for the time at which the alarm will be received by the fire brigade, as shown in Figure 10.3. The 2-minute section after the start of the parametric curve has been included to allow for failures of the detection/alarm system, where reliance is on the occupants to raise the alarm (i.e. assumed failure rate of approximately 17%).

With an operational detection, alarm and monitoring system and very long slow growth periods, intervention is likely to occur before flashover and, since the analysis is focused on potential flashover fires, these scenarios are not critical to the study.

10.6 Enclosure/Structural Model

The enclosure/structural multi-scenario model implemented for the mid-rise building comparative analysis is shown in Figure 10.4 and included the following sub-models:

- Fully developed enclosure fire sub-model
- FRL (distribution) sub-model
- FRL conversion sub-model
- Simple structural sub-model

The fire brigade suppression time is obtained from the fire brigade intervention model which is described in Section 10.7.

Outputs from the model include localised failure times and major (global) structural failure times, which are used as inputs to the Occupant Response Evacuation and Consolidation Model.

The major structural failure time can also be used in isolation for comparison of strategies in some applications.

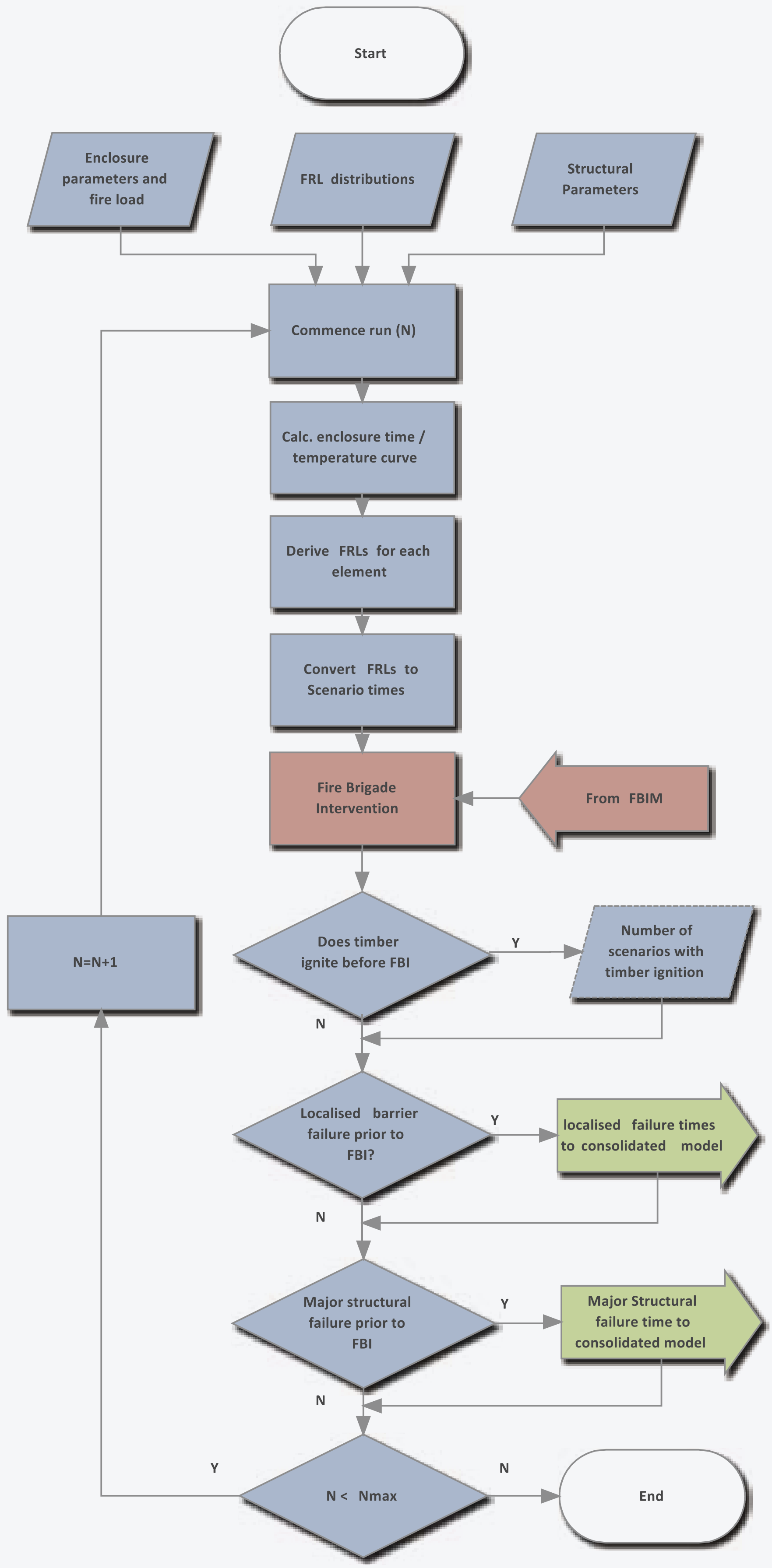


Figure 10.4: Enclosure/structural model.

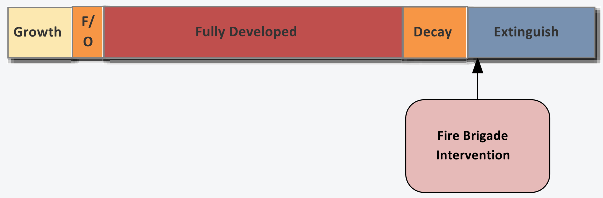
Typical examples of scenarios are shown on the timelines in Figure 10.5. The outcomes depend on the relative fire severity/duration, timing of fire brigade intervention and the efficacy of the fire-protective coverings/inherent fire resistance of the elements of construction.

Example 1

Prompt Fire Brigade Intervention before ignition of timber or barrier failure

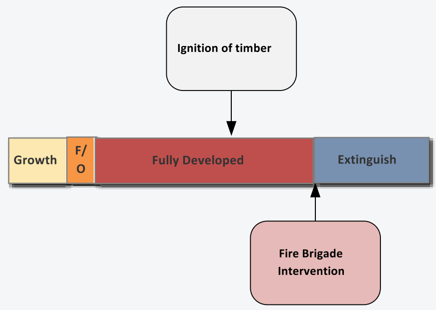
Example 2

Low duration / severity fire relative to protection of elements. Fire decays prior to fire brigade intervention



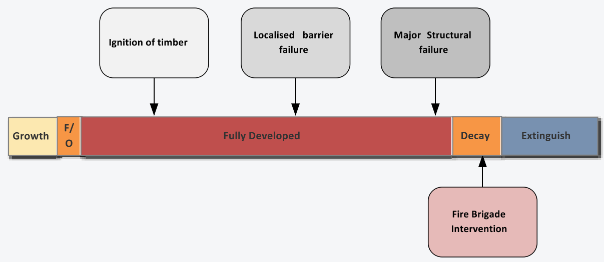
Example 3

Fire Brigade Intervention after ignition of timber element but before barrier failure.



Example 4

No fire Brigade Intervention prior to major structural collapse usually associated with two elements having gross defects causing premature failure.



Note: F/O - Flashover

Figure 10.5: Example abridged timelines for enclosure/structural model.

10.6.1 Fully Developed Enclosure Fire Sub-model

There are numerous closed form models that can be used to generate time/temperature regimes for post-flashover (fully developed) compartment fires based on fuel load, ventilation and thermal properties of boundaries; many of which have been reviewed by Hurley[21].

The method presented in Annex A of EN 1991-1-2:2002[22] was selected because it has also been codified and used extensively.

The method adopts the following equation to define a heating regime based on variables such as thermal properties of the boundary, ventilation conditions, enclosure dimensions and fire load.

$$\theta_g = 20 + 1{,}325\,(1 - 0.324e^{-0.2t^*} - 0.204e^{-1.7t^*} - 0.472e^{-19t^*})$$

A linear relationship is assumed for the cooling phase.

Refer to EN 1991-1-2:2002 for further details of the calculation method.

This model can be easily incorporated in a spreadsheet to run a multi-scenario analysis. Typical results are shown in Figure 10.8, with the standard fire resistance test and hydrocarbon heating regimes from AS 1530.4. The derivation of inputs is summarised below.

Fire load

A study was undertaken into fire loads and design fires for mid-rise buildings by Ocran[23] in 2012, providing the most relevant input data for this study since it supersedes an earlier study by Apte et al.[9] and it relates directly to mid-rise buildings.

Table 10.8 is a summary of Ocran's findings in relation to residential buildings

Table 10.8: Typical fire loads for residential buildings from Ocran[23].

	Fire Load Density (MJ/m²)		
Description	**Mean**	**95th Percentile**	**Maximum**
Residential buildings	370-550 (per room)	-	-
Living room	288-600	450-790	633-1700
Bedroom	534-944	712-846	738-1000
Dining room	393	576	901
Kitchens	807	940	1244

A range of fire load densities for residential occupancies is specified in guides/verification methods typically varying from 400 MJ/m² in the Verification Method: Framework for Fire Safety Design for New Zealand Building Code[24] to 780 MJ/m² in Eurocode 1 Parts 1-2[22].

To address the variability of fire load data, the analysis was undertaken using a fire load of 500 MJ/m² with a standard deviation of 150 MJ/m² supplemented by sensitivity analysis with distributions around mean values of 300 MJ/m² and 780 MJ/m², as shown in Table 10.9.

Table 10.9: Fire load distributions for apartment buildings.

Fire Loads	Fire Load MJ/m²	Standard Deviation MJ/m²	95 percentile MJ/m²	Min MJ/m²	Max MJ/m²
Low sensitivity	300	90	448	100	unlimited
Design value	500	150	747	200	unlimited
High sensitivity	780	115	970	200	unlimited

Note: If ignition of fire-protected timber was predicted, the fire load was increased to allow for a contribution to the fire load from the timber elements as detailed below:

- timber-framed construction – design fire load increased by 500 MJ/m²
- massive timber – total fire load of 2500 MJ/m² assumed.

Further information on the derivation of these values in included in Appendix G1 Contribution of timber elements to fire load.

Floor area

Ocran also reviewed literature to characterise typical room sizes, from which Figure 10.6 has been extracted. For the analysis, room floor areas were generated from the following uniform distributions for room width and length:

- width: 2.5 m to 5 m
- length 2.5 m to 8 m.

A typical distribution generated from these inputs is shown in Figure 10.7. It has the same general form as the results reported by Ocran (shown in Figure 10.6), but with a slight offset to larger room sizes. As the distributions for this analysis were selected to reflect modern building layouts – where kitchen lounge and study areas are often combined – this offset is expected and therefore the derived distribution is considered appropriate.

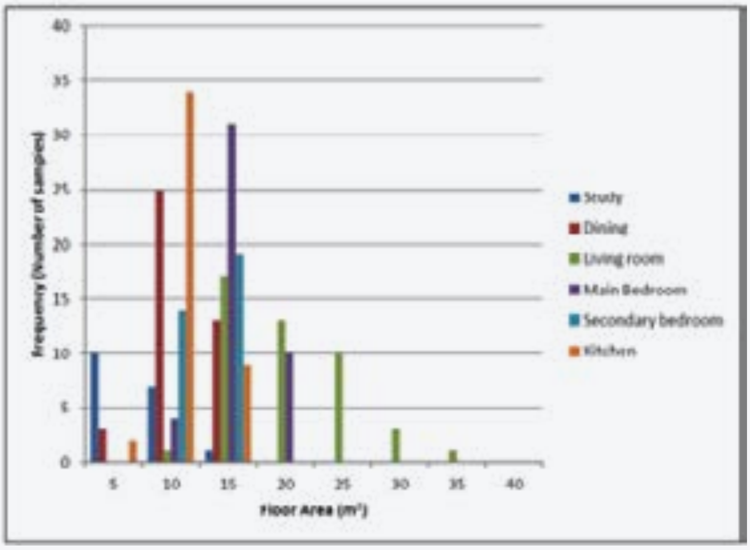


Figure 10.6: Frequency of floor areas in mid-rise residential buildings from Ocran[23].

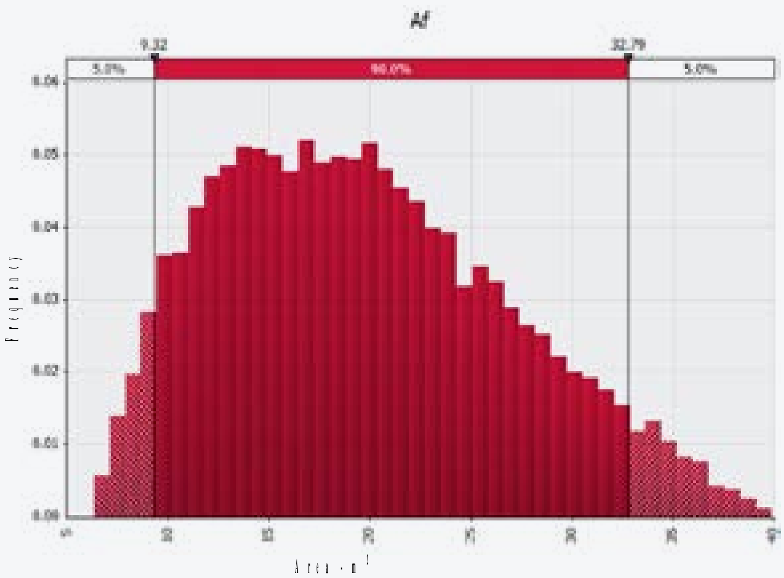


Figure 10.7: Floor area distribution derived for analysis of apartment buildings from uniform distributions for linear dimensions.

There are two approaches to defining the enclosure size to calculate the severity of a fully developed fire within an SOU. One approach is to assume no interior compartmentation and model the SOU as a single space; the other is to assume the interior walls within the SOU (some of which may not be required to be fire-resisting) remain intact and model the SOU as a series of rooms. Initially, and for a significant period post-flashover, the interior walls within the SOU would effectively subdivide the SOU; and therefore the latter approach was adopted and enclosure dimensions were based on a distribution of typical room sizes varying in area from 6.25 m^2 to 40 m^2. Since the study was comparative and a wide distribution of room geometries were considered, this assumption was considered reasonable.

Room height

A typical room height of 2.4 m was assumed to be representative for Class 2 and 3 buildings where floor to floor heights are optimised.

Opening area

The NCC Deemed-to-Satisfy requirements specify a minimum area of natural light of $0.1xA_f$ where A_f is the floor area[25]. This would therefore be a reasonable lower bound ventilation area for an apartment room. Energy Efficiency requirements are introducing practical limits to window areas in many jurisdictions in Australia. Maximum window sizes of 41% of the floor area were derived in an analysis of the impact of increasing the regulatory requirements relating to energy efficiency of buildings in 2009[25]. Based on this information, a uniform (rectangular) distribution of openings areas from 10% to 41% of the floor area was assumed.

Ocran reported the measurement of window sizes taken during a survey of multifamily dwellings yielded an average of 3.1 m^2, a minimum of 1.1 m^2, and a maximum of 8.0 m^2 for living rooms. If it is assumed that the maximum window size relates to the largest room size, the maximum opening area would be about 23% of the floor area. If this is applied to a more frequent room area (20 m^2) (refer Figure 10.7), the maximum opening area would be about 40% of the floor area. The minimum window size (1.1 m^2) applied to a small room area (10 m2) represents 11% of the floor area. These results are therefore considered reasonably consistent with an assumed uniform (rectangular) distribution of opening areas from 10% to 41% of the floor area.

Opening Height

A uniform distribution varying from 0.3 m to 2.1 m was assumed for opening heights to address the range used in contemporary buildings.

Lining properties

The following lining properties were used for the enclosure boundaries:

- thickness – 26mm
- thermal conductivity – 0.27 W/m.K
- density 900kg/m^3
- heat capacity 2000 J/kg.K (allows for combined water).

Pre-flashover growth rate

A fast pre-flashover fire growth rate was assumed to account for the impact of contents such as upholstered furniture, mattresses, etc; however, as the fires tended to be ventilation controlled this assumption was not critical.

Typical outputs

Typical outputs from the fully developed fire enclosure model are shown in Figure 10.8, compared to the standard and hydrocarbon AS 1530.4 heating regimes.

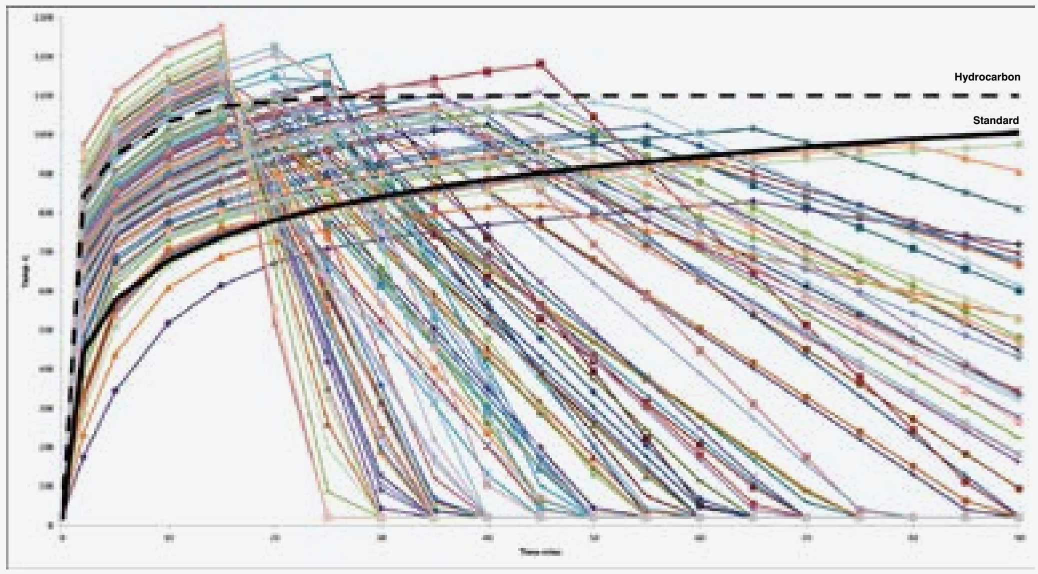


Figure 10.8: Typical enclosure temperatures for design value case (500 MJ/m²) compared to standard and hydrocarbon heating regimes.

The methods described below were used to equate the exposure to the calculated enclosure temperatures to the standard heating regime. For the 500 MJ/m² case, the exposure from about 97% of scenarios was less than or equal to the equivalent of a 90-minute standard fire resistance test, and the exposure from 75% of the scenarios was less than or equal to the equivalent of a 60-minute standard fire resistance test.

These results can be considered to be generally consistent with the current NCC Deemed-to-Satisfy Provisions for mid-rise Class 2 and 3 buildings, which generally require 90/90/90 FRLs for loadbearing elements and -/60/60 for non-loadbearing elements.

Modelling contribution of fire-protected timber to the fire load

If the relevant RISF or MRISF temperature criteria of 250°C and 300°C, respectively, were not exceeded, it was assumed that there would be no increase in fire severity resulting from the use of fire-protected timber. The validity of this assumption was demonstrated in the test described in Appendix A4.

An initial Monte Carlo simulation run was undertaken to determine the proportion of scenarios where the fire is suppressed or burns out prior to failure of a timber-framed element.

For the proportion of scenarios where the timber ignites, the following approaches were adopted:

- For timber-framed construction the fire load will be increased by 500MJ/m².
- For massive timber panels the total fire load was assumed to be 2500 MJ/m².

Details of the basis for the selection of this approach are provided in Appendix G1.

10.6.2 FRL (Distribution) Sub-model

A two-peak distribution was adopted for the FRL of elements of construction.

The primary peak is centred on the nominated/typical FRL for the element with a standard deviation of 10% of the nominated FRL. The secondary peak is centred on the performance, assuming a gross defect is present, with a standard deviation of 10% of the estimated FRL of an element with a gross defect. The probability of a gross defect occurring in a single element was assumed to be 0.005.

The FRLs shown in Table 10.10 were assumed for the structural elements.

Table 10.10: Mean FRLs adopted for elements with gross defects.

Case	Mean FRL – Struct. Ad/Integrity/Insulation – min			
	Loadbearing		Non Loadbearing	
	No defect	Major defect	No defect	Major defect
Control (protected steel)	90/90/90	26/26/26	-/60/60	-/22/22
Timber frame	90/90/90	22/22/22	-/60/60	-/22/22
Massive timber	90/90/90	60/60/60	-/75/75	-/60/60

Due to the high inherent fire resistance of massive timber panels the impact of major defects such as substitution of non-fire-protective coverings has a lesser impact on the fire resistance. Further details of the derivation of the above FRLs is provided in Appendix G2.

10.6.3 Fire Resistance Levels to Scenario Time Conversion Model

In most instances, the time to failure of an element of construction ascertained in a standard fire resistance test will differ from the failure time if the element is exposed to a real or simulated fire scenario (e.g. Annex A of EN 1991-1-2:2002), because the time temperature histories will differ (as shown in Figure 10.8).

A method based on the Equal Steel Temperature concept was developed in which a “target protected steel element” with specified thermal properties was defined and the time temperature history calculated at a critical point based on exposure to the fire scenarios and the standard heating regime. Equivalent exposure was deemed to have occurred when the critical part of the element reaches the same temperature under the different heating regimes.

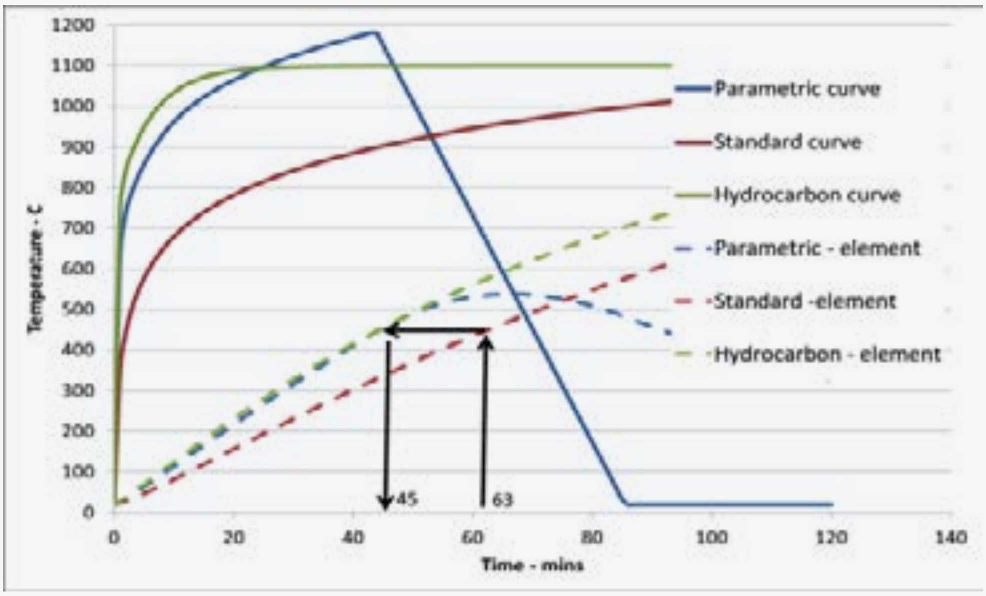


Figure 10.9: Conversion of fire resistance period to fire scenario time.

The process is shown graphically in Figure 10.9. If it is required to determine the time to failure of an element that achieved an FRL of 63/-/- when exposed to the fire scenario (parametric curve) fire, the following approach is adopted:

- The target element attains a temperature of 454°C when exposed to the standard fire resistance test for 63 minutes.
- The target element would need to be exposed to the fire scenario for 45 minutes to attain the same temperature.
- Therefore, the fire scenario failure time would be 45 minutes.

Further details of the method, selection of target element and comparison of predictions with experimental data are provided in Appendix G3.

10.6.4 Simple Structural Model

To evaluate the risk of a major collapse of a structure or part of the structure, it is first necessary to determine which structural elements or combinations of structural elements may initiate a major collapse. For medium and high-rise buildings, many design codes require robust designs to address the risk of disproportionate collapse, which can be achieved by incorporating redundancy in the design such that for collapse to occur more than one key structural element needs to fail.

When considering collapse of a structure exposed to fire, the potential for defects to cause premature failures needs to be considered. However, the probabilities of more than one member having a defect may be sufficiently low that no additional special measures may be required. In other words, the risk associated with defects needs to be evaluated – even if protection to structural members is specified to resist full burnout of a fire.

NCC performance requirement BP1.1 states:

"(a) A building or structure, during construction and use, with appropriate degrees of reliability,

must –

(i) perform adequately under all reasonably expected design actions; and

(ii) withstand extreme or frequently repeated design actions; and

(iii) be designed to sustain local damage, with the structural system as a whole remaining stable and not being damaged to an extent disproportionate to the original local damage; and

(iv) avoid causing damage to other properties, by resisting the actions to which it may reasonably expect to be subjected."

It was therefore considered reasonable to assume that the structure of the control and subject buildings will be designed in accordance with these provisions and that a level of redundancy will be provided in the design, such that for collapse to occur more than one key structural element needs to fail.

Simple structural layouts for timber and steel versions of the generic apartment building are shown in Figure 10.10 and Figure 11.11.

By considering fire-resisting loadbearing walls as a series of segments and assuming any supporting beams are incorporated in floor elements, a typical timber building apartment structure can be simplified to six structural wall elements and three structural floor elements.

When considering structural adequacy, a typical concrete and steel masonry building apartment can be represented as six columns and three floor units.

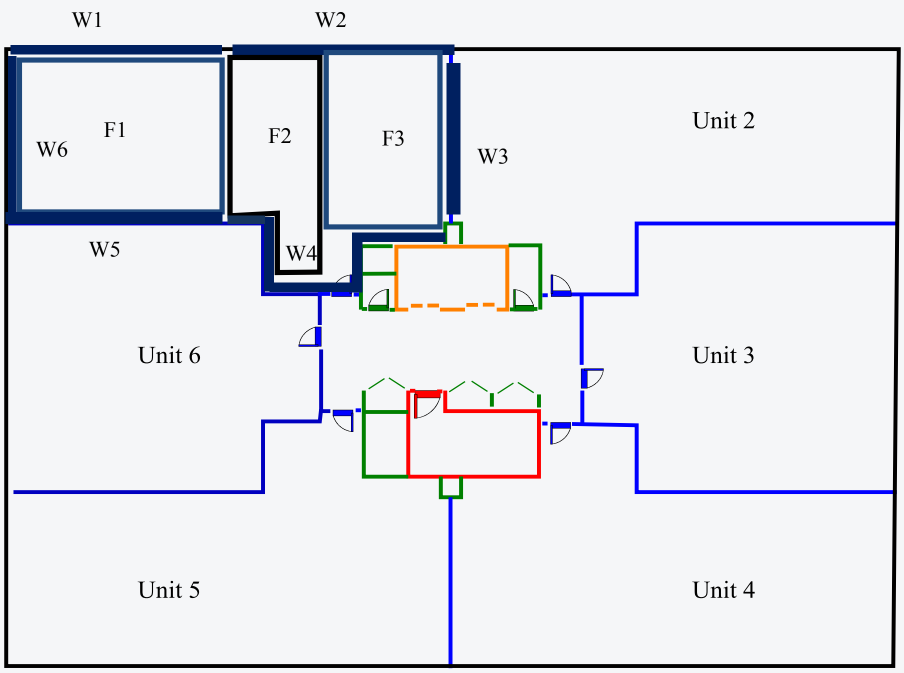


Figure 10.10: Schematic showing simple structural layout for an apartment in a timber building.

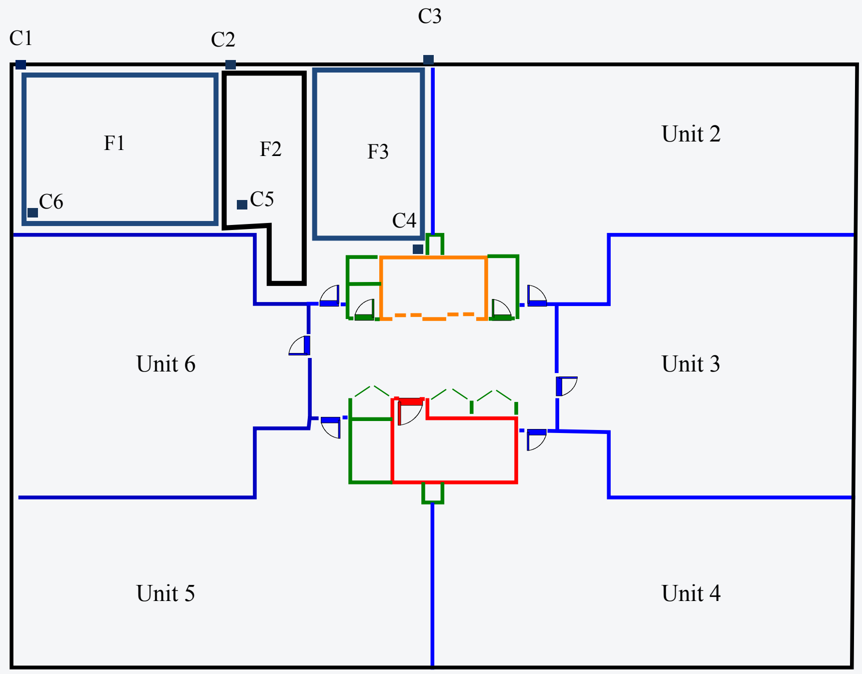


Figure 10.11: Schematic showing simple structural layout of an apartment in a steel building.

For a major structural failure to occur, it was assumed at least two members are required to fail from the nine structural members. This simplification is considered appropriate for a generic comparative analysis but, for specific buildings, a more detailed structural analysis may be appropriate.

10.7 Fire Brigade Intervention Modelling

Fire brigade intervention is an important part of the analysis since it can influence:

- fire duration/fire severity (fire-fighting activity)
- building evacuation time (search and rescue activities).

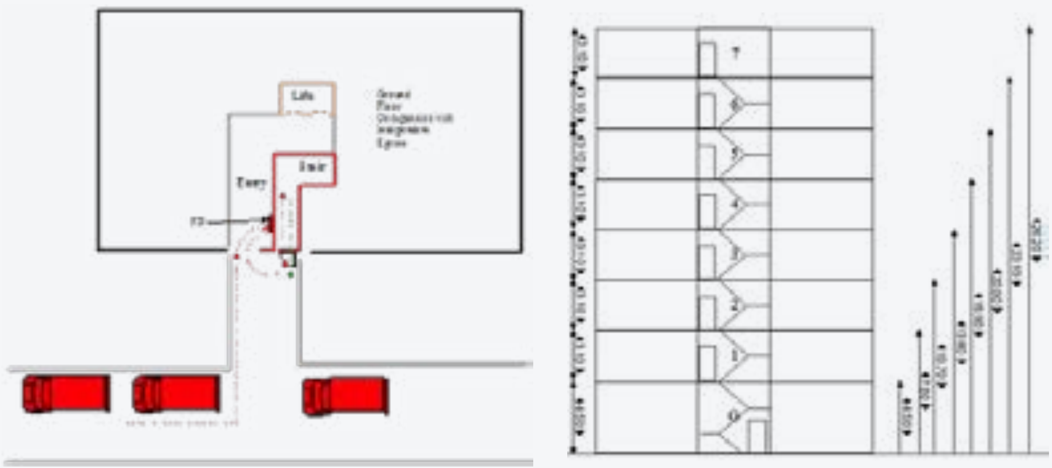
Distributions of the time to commencement of fire-fighting activities were derived as part of the Monte Carlo simulations and input into the enclosure/structural model for each simulation to determine:

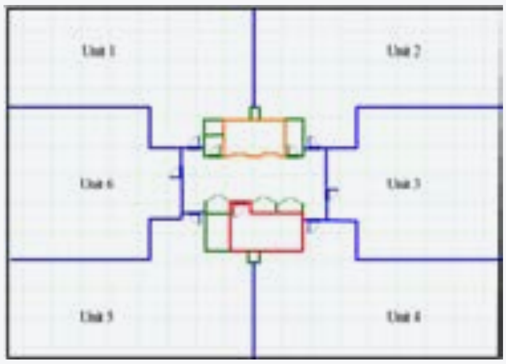
- if fire brigade intervention occurs prior to a major structural failure, if burnout has not already occurred
- if fire brigade intervention occurs prior to failure of the compartmentation, if burnout has not already occurred
- if the fire-protected timber members have ignited beneath the fire-protective coverings, if burnout has not already occurred.

To model search and rescue activities, it was necessary to integrate some aspects of the fire brigade intervention model with the occupant response, evacuation and consolidation model.

10.7.1 Building Layout Features for Fire Brigade Intervention Model

The building layout details that were used for the fire brigade intervention modelling of the generic mid-rise Class 2 or 3 building are shown in Figure 10.12.





Travel Distances

Appliance to main door - **20m**

Main door to FIP - **5m**

FIP to base of stair -**12m**

Steps:

Ground to L1 - **26**

All other Levels **18 steps** plus **4m** horizontal / floor

Travel from stair to Apartment of Fire Origin door - **6m**

Figure 10.12: Building layout and critical dimensions for fire brigade intervention modelling.

10.7.2 Fire Brigade Intervention Model Overview and Inputs

The fire brigade intervention model was adapted from the fire brigade intervention model (FBIM)[17] developed by AFAC but modified to facilitate Monte Carlo simulations as part of a model incorporating fire severity and structural performance. Other modifications were made based on further verification of the FBIM model undertaken by Claridge[27] and to base the response times on data from the 2014 Report of Government Services[28].

Key inputs are summarised in Table 10.11, which also references the source for the input.

Refer to Appendix G4: Verification of Stair Climbing Component within the implementation of the fire brigade intervention model used for comparison of predicted stair climbing times against international studies.

Table 10.11: Summary of fire brigade intervention model inputs.

Description	Input Type	Values	Comments
First alarm to call centre (Class 2)	Rect. Dist.	0 to 240s	Time relative to parametric curve (no alarm monitoring). From Table 10.7
First alarm to call centre (Class 3)	Rect. Dist.	-1200 to 120s	Time relative to parametric curve (detection alarm monitoring) From Table 10.7
Time for receipt of information	Fixed	60s	From FBIM Table C
Time taken to dispatch resources	Fixed	0s	Published data based on time of call used to establish fire brigade response time so already included in time to reach curb side
Time to reach curb side	Truncated Log Normal	Mean 500s SD 230s Min 180s	Derived from the average reported response times for each state in the 2014 Report of Government Services of 7.65mins (50 percentile) and 13.33 mins 90 (percentile) with allowance for note taking time added to South Australian Figures
Time to don BA	Truncated normal dist.	Mean 88s SD 34.1 Min 44	From FBIM Table M
Pick up forced entry tools	Truncated normal dist.	Mean 25s SD 13 Min 13	From FBIM Table P Critical path forced entry tools selected because longer time than high-rise pack. SD Estimated.
Open door with master key	Fixed	10s	From FBIM Table J
Check FIP and to resolve way finding	Fixed	60s	From FBIM Table L and Table K
Initial OIC actions			Coincide with above
Set up additional water supply			Undertaken while other activities underway
Walking speed – horizontal	Truncated Log Normal distribution	Mean 1.39m/s SD 0.57 m/s Min 0.28 m/s Max 3.3m/s	Based on FBIM Graph Q3 full turnout with BA
Walking speed – horizontal through smoke	Truncated Log Normal distribution	Mean 0.7/s SD 0.3 m/s Min 0.14 m/s Max 1.66m/s	Half values without smoke
Stair climbing levels 0 – 10	Normal distribution	Mean 1.3 steps/s SD 0.2 steps/s Min 0.43 steps/s Max 1.68 steps/s	Based on Claridge with some adjustments
Stair climbing levels 10 – 20	Normal Distribution	Mean 500s SD 230s Min 180s	Based on Claridge with some adjustments
Stair climbing levels 10 – 20	Normal Distribution	Mean 500s SD 230s Min 180s	Based on Claridge with some adjustments
Stair climbing levels 20+	Normal Distribution	Mean 1 step/s SD 0.25 steps/s Min 0.5 steps/s Max 1.4 steps/s	Based on Claridge with some adjustments
Rest and recovery period L6 to 10	Rectangular for N>6	Min 0 Max 15(N-6)s	Not applicable below 6 levels N= number of floors
Hindrance factor	Factor	50% increase in travel time to set up position	FBIM Table S Hindrance caused by occupants evacuating to movement of fire fighters. Since the number of occupants/stair is relatively small (limited by travel distance to stairs and building height) the risk of hindrance is low; however, the fire fighter travel time within the stairs has been increased by 50% to account for potential delays
Set up hose 1	Truncated log Normal	Mean 40.9s SD 17.7s Min 14s Max 90s	Level below fire floor FBIM Table v5.2
Force open door to SOU of fire origin	Fixed	30s	FBIM Table I

10.7.3 Fire Brigade Intervention Model Time to Water Application Outputs

Typical times to application of water relative to the start of the parametric fully developed fire scenarios, without and with monitored detection and alarm systems predicted by the modelling, are shown in Figure 10.13 and Figure 10.14, respectively.

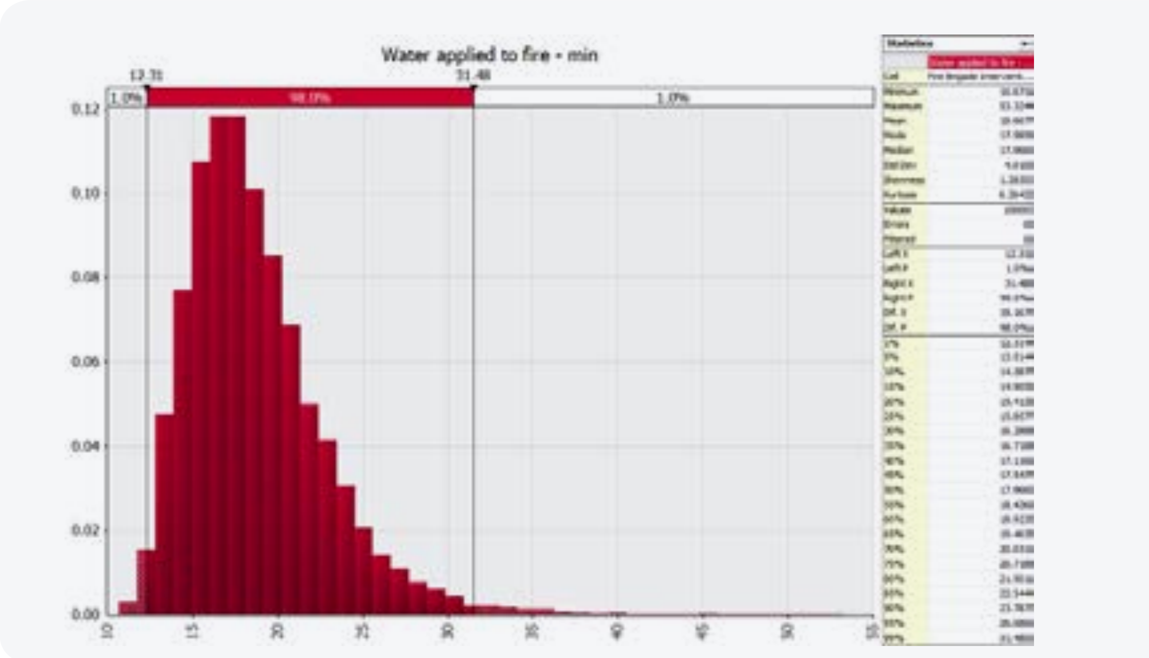


Figure 10.13: Distribution of time to application of water for fire on Level 5 without a monitored detection and alarm system.

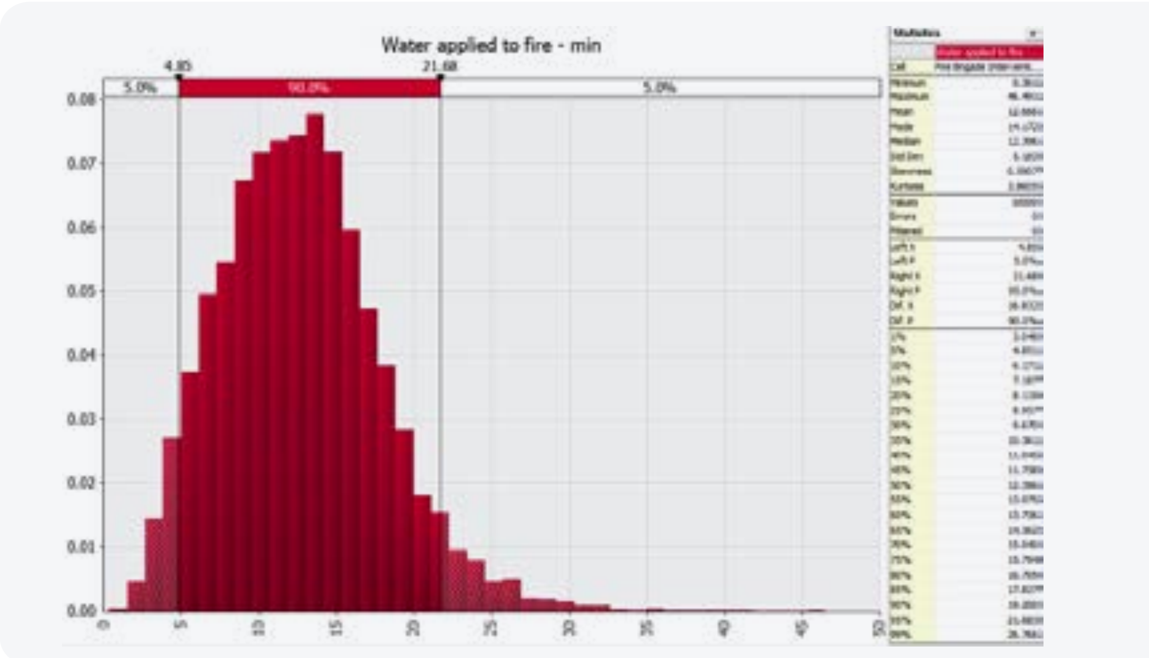


Figure 10.14: distribution of time to application of water for fire on Level 5 with a monitored detection and alarm system.

10.7.4 Fire Brigade Search and Rescue Activities Class 2 and Type 1 Class 3 Occupancies

Coincident with attacking the fire, other fire service teams would be undertaking search and rescue activities. The priorities for these activities would vary, depending on the specific circumstances of a fire event. Therefore a generalised approach has been adopted for this analysis, to enable the activities to be integrated into the occupant behaviour, evacuation and tenability sub-model described below, facilitating the analysis of the building design options as part of a stochastic analysis. The approaches taken and allocated times are shown in Figure 10.15.

The occupant behaviour, evacuation and tenability sub-model establishes tenability conditions in the building for various combinations of door open/closed states, which are then modified based on the behaviour of fire-resistant elements of construction exposed to the fully developed fire. Evacuation of occupants is modelled in a stochastic manner varying with time and a proportion of occupants are assumed to be unable to evacuate without assistance.

Also, it is assumed that if occupants encounter smoke they return to their apartment and wait for assistance.

Occupants waiting for assistance are considered to be evacuated when the search and rescue activities for a specific floor are completed. Fixed times of 800s for the fire floor and 360s for other floors have been assumed, which were calculated on the following basis:

- search of a 90m^2 smoke-filled SOU on the fire floor: $90/0.16 \approx 560$s (using FBIM mean value for searching a smoke-filled room)
- search of the remaining 4 SOUs on the fire floor, which were assumed to be clear of smoke but required doors breaking open to check they were unoccupied (an allowance of 30s for forced entry plus 30s for checking each apartment was made), i.e. 240s for four SOUs
- each of the other floors contains 6 apartments (i.e. approx. 360s).

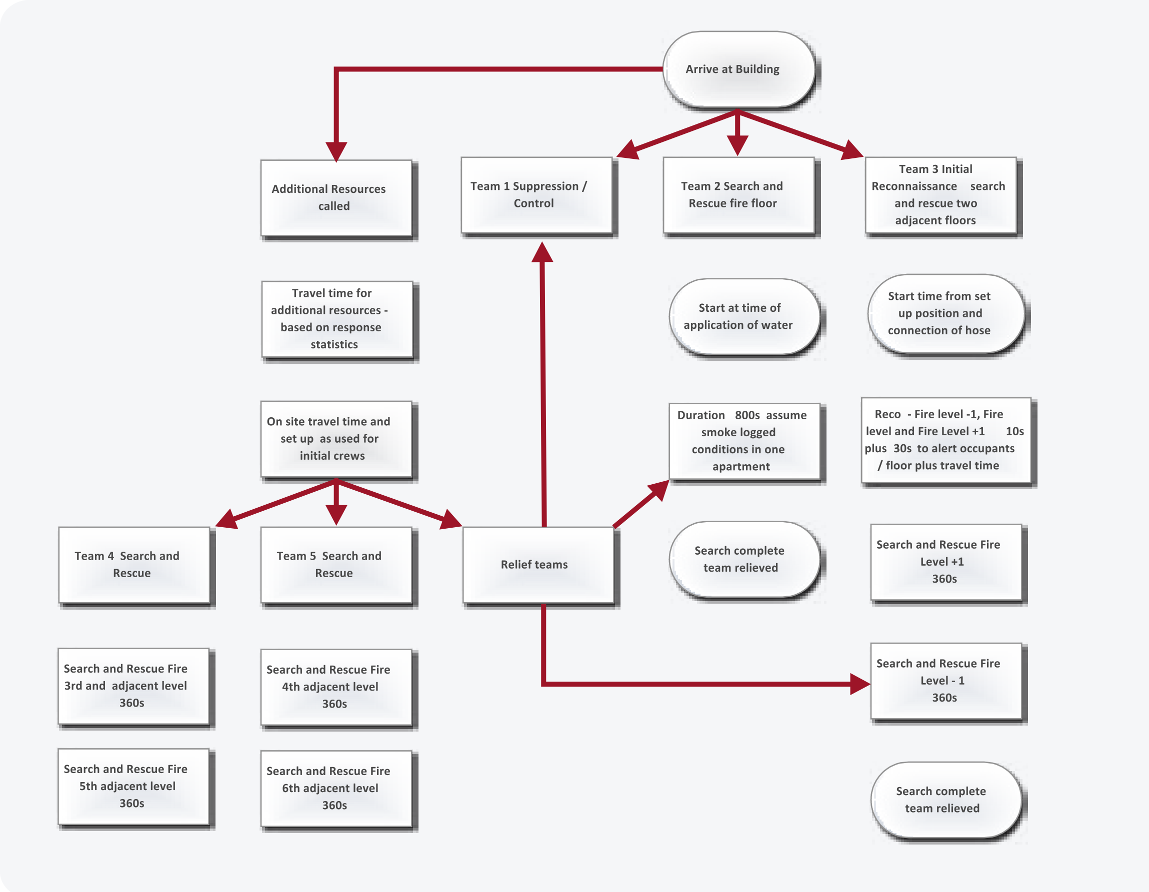


Figure 10.15: Fire brigade search and rescue flow chart Class 2 buildings.

10.7.5 Fire Brigade Search and Rescue Activities Type 2 Class 3 Occupancies

For the Class 3 building with Type 2 occupants, the situation facing fire fighters would be different to a Class 2 building. There would normally be an emergency management structure in place and doors would be unlocked. Staff would be able to inform fire fighters of occupants remaining in the buildings, so activities are concentrated more on rescue than evacuation. It will be assumed that Teams 2 and 3 focus on the floor of fire origin rescuing the four remaining residents of the group requiring assistance on that floor.

FBIM specifies an average speed of 0.05 m/s through smoke, which has been adopted for this analysis. A travel distance of 15 m to the stair is assumed (approx. 6 m between the SOU and stair and 9 m within the SOU) which equates to 300 s. It will be assumed that one fire fighter can assist one occupant at this speed (i.e. a team of three can evacuate two occupants simultaneously with the third fire fighter on a hose).

The allocation of resources is shown in Figure 10.16. The time allocated for rescue on floors without smoke may be considered overly conservative; however, it has been retained to allow for unforeseen events and allow the broadest application of the results. Physical assistance from staff with evacuation of occupants requiring assistance on non-fire floors has also been ignored.

Substantial additional fire brigade resources are required to support the initial response in the model. These additional resources will only be required for no sprinkler/fail sprinkler protection options, and very rare scenarios where global collapse of the structure may be imminent. Such additional resources may not be readily available in isolated areas, but medium-rise care facilities are relatively rare and tend to be located in highly populated areas. Medium-rise construction would not be a preferred model for housing large populations of people requiring high levels of support. Therefore the configuration adopted, and assumed resources to respond, were considered to be reasonable.

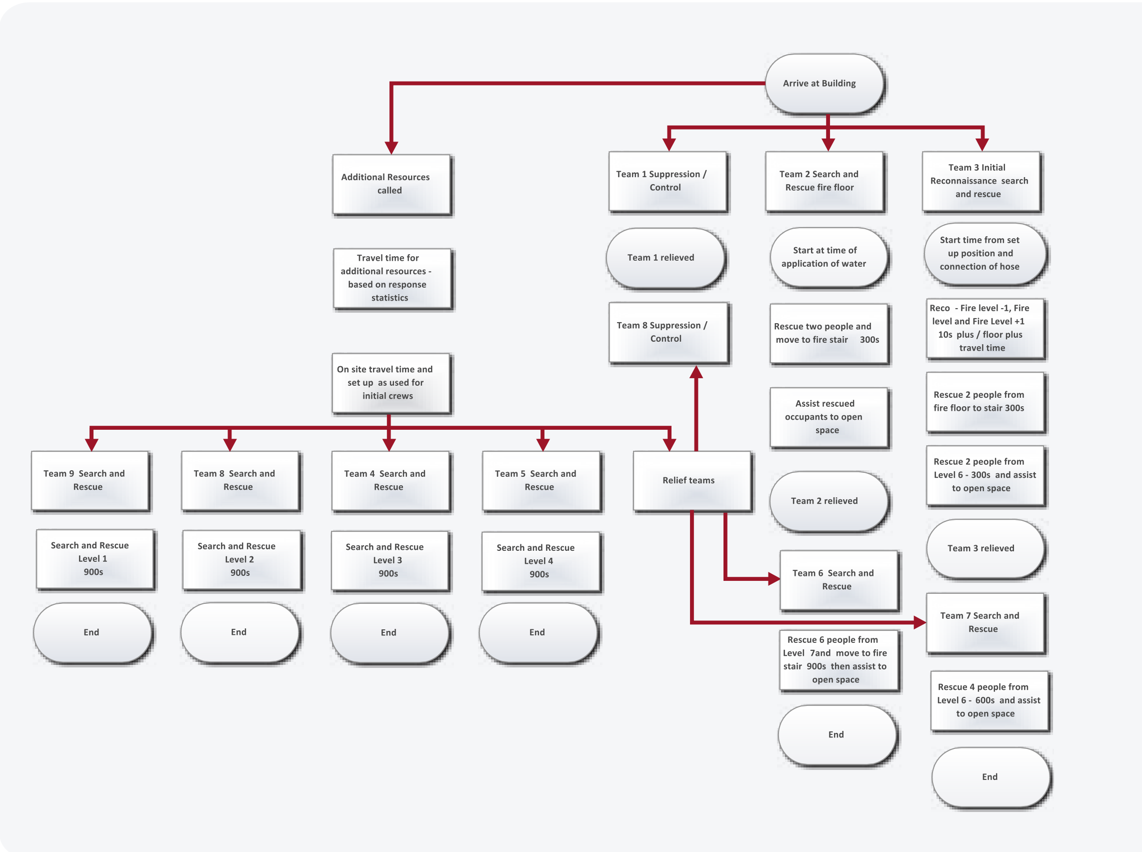


Figure 10.16: Fire brigade search and rescue flow chart Class 3 building with Type 2 occupants.

10.8 Occupant Response Evacuation and Consolidation Model

10.8.1 Occupant Characterisation for Class 2 and 3 Occupancies

The occupant characteristics of Class 2 buildings (e.g. apartments) were considered to be broadly representative of the Australian community.

This profile was also applied to the following Class 3 occupancies which were defined as Class 3 Type 1 occupants:

- Class 3(a) – a boarding house, guest house, hostel, lodging house or backpackers accommodation
- Class 3(b) – a residential part of a hotel or motel
- Class 3(e) –a residential part of a health-care building which accommodates members of staff.

These Class 3 buildings may have improved emergency management systems in place, but the impact of these was conservatively assumed to have no positive effect offsetting the potentially higher fire risks associated with some Class 3(a) occupancies.

The same evacuation model was therefore used for Class 2 and Class 3(a), (b) and (e) occupancies.

Evacuation modelling assumed that the occupants of each SOU would evacuate as a group. For apartments, an average group size of 2.5 was assumed. For some Class 3 occupancies, larger group sizes may apply. An average value of 6.5 per SOU for Class 3 occupancies was generally assumed.

Class 3(d) occupancies (accommodation for the aged, children or people with disabilities) have larger proportions of people that will require assistance to evacuate, and hence present a greater fire risk, and are referred to as Type 2 occupants. In these instances some level of staff assistance will be required to facilitate evacuation, which may vary from simply providing direction to providing physical assistance to occupant(s) who may or may not be aware of the emergency.

These two cases were considered to bracket other Class 3 building types and therefore a separate analysis was undertaken on each of these cases.

10.8.2 Occupant Response and Evacuation Model for Class 2 and Class 3 Type 1 Occupancies

A simple probabilistic model was applied that incorporates distributions for pre-movement times and can be incorporated into a multi-scenario analysis to address the variability of human responses to fire (See Appendix G5: Occupant Behaviour Review).

The response times (times to begin evacuation) were assumed to follow the simple distributions shown in Figure 10.17, which were modelled as discrete distributions with one-minute intervals. The parameters A-D will vary depending on the proximity to the fire, provision of general building alarm system, type of alarm system, etc. The values assumed for the comparative study of mid-rise buildings are summarised in Table 10.12 and are based on a poor/no alarm scenario, since they are applied to occupants outside the SOU of fire origin. A separate analysis based on fire data was undertaken for the apartment of fire origin (See Section 6).

The evacuation was assumed to commence at the start of the parametric fully developed fire scenario, (t=0) at which stage strong unambiguous cues outside the apartment of fire origin would be received reinforcing any building alarm system that had been activated.

This means that the number of outcomes during period B (B–n) would be equal to the period B in minutes plus 1 since the outcome interval is 1 minute and evacuation starts at t=0. For period D the number of outcomes is equal to the time period in minutes.

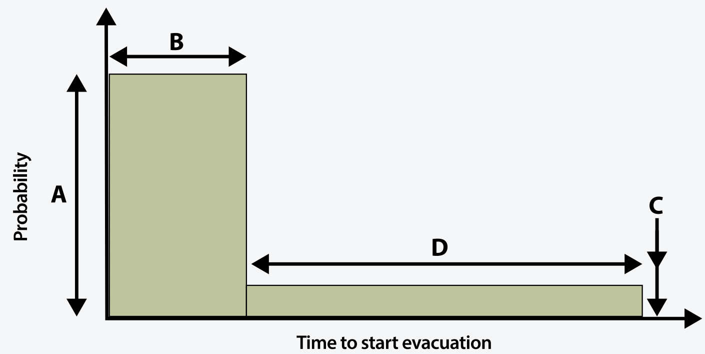


Figure 10.17: Occupant response model.

Table 10.12: Input parameters for occupant response model.

Location	A – prob	B – min	B -n	C – prob	D – min	D -n	No response	Notes
Apartment of fire origin	-	-	-	-	-	-	-	Not applicable
Remainder floor of fire origin	0.132	5	6	0.0079	25	25	0.011	Very strong secondary cues
Two adjacent floors to floor of fire origin	0.072	10	11	0.01	20	20	0.008	Very strong secondary cues
Other floors	0.036	20	21	0.01	20	20	0.044	Strong secondary cues

Due to the relatively low population and lengthy evacuation, the flow of people through stairs would be expected to be unconstrained and therefore the following average travel speeds were assumed:

- horizontal travel clear or light smoke:0.6 m/s to 1.2 m/s (for the subject building it will be assumed that it will take 10 s for occupants to move from their apartment to the stair door and a further 10 s horizontal travel to the exit from the base of the stairs)
- stair travel 20 s/floor.

The model assumed each SOU evacuates as a group.

Figure 10.18 shows the evacuation times (i.e. response plus travel times) with no impact from a fire. The distribution obtained is consistent with observed performance in fire drills and fire events, comprising an initial peak and then low evacuation rates over an extended period (see Appendix G5: Occupant Behaviour Review). The model also incorporates a probability that some occupants will not evacuate, allowing for people who require assistance to evacuate.

The evacuation model assumes that if occupants encounter smoke they would return to their apartment to await assistance. If untenable conditions occur in the apartment or global collapse is predicted prior to fire brigade search and rescue activities, they will be deemed to have been exposed to untenable conditions.

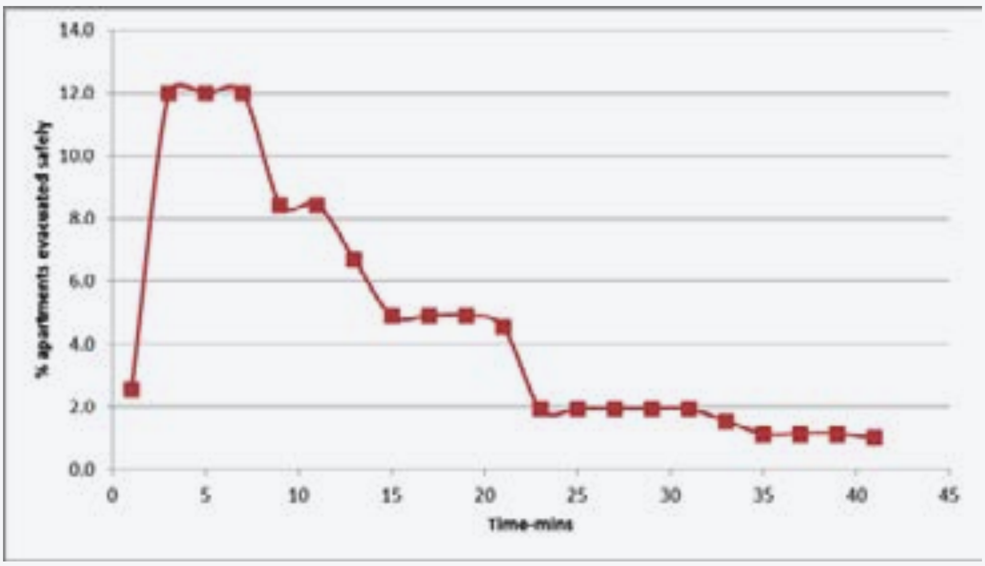


Figure 10.18: Evacuation times with no adjustment for impact of fire (base case).

10.8.3 Occupant Response and Evacuation Model for Class 3 Type 2 Occupancies

Accommodation housing Type 2 occupants will require higher staff levels and an emergency management structure consistent with the number of occupants requiring substantial assistance. Thus the evacuation process will tend to be more controlled, less random and more deterministic than in Class 2 buildings and some Class 3 Type 1 buildings.

In these occupancies, the fire brigade would be notified of the fire emergency by a call from the monitored alarm and detection service shortly after the building alarm was activated. Also at this stage, staff would be alerted, providing additional preparation time during the early stages of a fire in most cases, prior to the rapid growth and flashover phase simulated in the parametric heating regime assumed for fully developed fires.

The assumed staff response after making calls to emergency services, etc, would be to alert occupants, facilitate evacuation of those capable of self-evacuating and start evacuation of those under immediate threat (i.e. on the fire floor).

Based on these activities, it was assumed that the staff would have alerted and prepared occupants such that evacuation of the high dependency group of occupants on the fire floor would commence at t=1 min (i.e. 1 minute after commencement of the parametric heating regime) if safe to do so, leaving four high dependency occupants of the original 6.5 to be evacuated on the fire floor with assistance from the fire brigade.

On all other floors, six high dependency occupants would be assumed to require fire brigade assistance to evacuate (typically one group of occupants).

A managed evacuation process for the remaining occupants who do not require physical assistance to evacuate was modelled adopting the following parameters:

- Travel time to descend stairs is 40 s/level plus 20 s for horizontal travel.
- Fire floor evacuation starts at t=60s.
- Next floor starts evacuation once the previous floor has exited the building.
- Order of evacuation is Level 5,6,7,4,3,2,1 (assuming a fire on Level 5).
- If occupants encounter smoke they would return to SOU and wait for assistance.

Ignoring the impact of smoke, these assumptions yield the evacuation times for the occupants excluding those reliant on fire fighters for evacuation presented in Table 10.13.

Table 10.13: Timing of phased evacuation.

Building level	Time to exit SOU – min	Time to exit building – min
7	9.0	14.0
6	4.7	9.0
5	1.0	4.7
4	14.0	17.0
3	17.0	19.3
2	19.3	21.0
1	21.0	22.0

The outcomes from the evacuation model without the impact of smoke are shown in Figure 10.19. The early evacuation relates to the SOU of fire origin, which is not relevant to the analysis outside the SOU of fire origin. The graph output excludes about 18% of the occupants, who are assumed to require assistance from the fire brigade to evacuate.

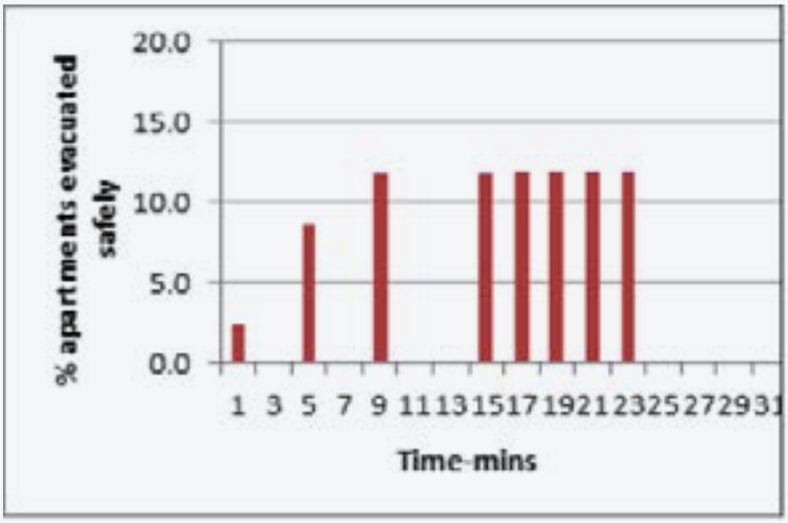


Figure 10.19: Evacuation outcomes ignoring impact of smoke.

10.8.4 Consolidation

The logic behind the consolidation model is shown in the form of a flow chart in Figure 10.20.

For each fully developed fire scenario (chosen at random), the time to untenable conditions and loss of visibility is input from the base smoke-spread model.

Detection/alarm times are then used as input to develop distributions for the response of occupants and fire brigade intervention as described above.

Occupants of each SOU are assumed to evacuate as a group and, if they encounter heavy smoke (loss of visibility), they are assumed to return to their SOU and await fire brigade assistance to evacuate. This is a simplification, since records from fire incidents indicate that under some circumstances occupants will try and evacuate through smoke with varying degrees of success. Since the purpose of the analyses was to compare the safety outcomes with those associated with designs meeting the Deemed-to-Satisfy (DTS) Provisions, a simple approach was considered reasonable.

If untenable conditions occur in an occupied SOU, the occupants are deemed to be exposed to untenable conditions. Also, any occupants in the building at the time of global collapse predicted by the enclosure fire/ structural model are assumed to be exposed to untenable conditions. Failure of two elements was deemed to initiate substantial failure (global collapse) and all remaining occupants are assumed to be exposed to untenable conditions.

The analysis is repeated for each scenario in the multi-scenario analysis and the number of occupancy groups exposed to untenable conditions in each scenario recorded.

Figure 10.20: Class 2 and Class 3 Type 1 evacuation model flow chart.

10.9 Summary of Results from Monte Carlo Analysis

10.9.1 Class 2 Building Occupant Safety Results

Monte Carlo analyses were undertaken for apartment fires occurring on Levels 2, 5 and 7, the results from which were consolidated on the following basis:

- Level 2 fire is representative of fires on Levels 1-3
- Level 5 fire is representative of fires on levels 4-6
- Level 7 is included as the floor with the longest time for fire brigade intervention but represents a special case since no occupants occupy the level above.

Monte Carlo analyses were undertaken for a control steel-framed building, a timber-framed building and a massive timber building. The timber buildings were modelled with and without increased fire loads, with the results being combined based on the estimated proportion of fires that could ignite the timber substrate and may affect fire severity. The impact of defects was incorporated in the fire resistance sub-model.

Finally, the results of the timber buildings were adjusted to take into account the presence of automatic fire sprinklers. The fire sprinklers were assumed to have a reliability of 92% and, if they operated successfully, tenable conditions would be maintained in all adjoining fire compartments and no fire spread would occur.

The results are expressed in terms of the number of occupant groups exposed to potentially untenable conditions where an occupant group represents the occupants of an apartment (assumed to be equivalent to 2.5 people per apartment).

Due to the large number of variables and low frequency of key events, 100,000 scenarios were run for each configuration.

The above results were consolidated by combining the individual Level results using the following relationship:

- Building Consolidated results = ((Level 2 x 3) + (Level 5 x 3) + Level 7)

The frequency of potential flashover fires was estimated to be 1.8 x 10^{-4} fires/annum/apartment and therefore the frequency for the subject building (42 apartments) was assumed to be approximately 7.56 x 10^{-3} fires /annum.

The results were further consolidated by grouping scenarios where one to three occupant groups were exposed to untenable conditions and four or more; which approximates to less than 10 occupants and 10–100 occupants respectively enabling the results to be expressed in a format that can be compared to F-N curves. It should be noted that the occupants of the apartment of fire origin are excluded from this analysis.

Table 10.14: F-N Consolidated results for Class 2 buildings.

No of occupants exposed to potential untenable conditions	Frequency/annum x 10^{-6}		
	Control	Timber Frame	Massive Timber
1-10	164.7	13.2	12.1
10-100	3.62	0.41	0.01

The frequencies of exposure in Table 10.14 are much higher than may be expected from consideration of historic fire losses if they are assumed to represent fire fatalities. This variance can be largely explained by a number of conservative assumptions that have been made in the analysis, namely:

- The assumption that occupants are largely passive if smoke spread occurs to their apartment through, for example, an open door. In most instances they would be likely to take actions to mitigate the risk, such as closing doors, seeking refuge on a balcony or in a room within the apartment.
- The global structural model is simplistic since it is for a generic application, and an assumption has been made that the entire building is lost upon failure of two members, which may not be the case.
- The proportion of open doors was based on the very limited data in literature and for apartment buildings, the probability of SOU doors being closed could be much higher than the 90% assumed for the apartment of fire origin and 95% assumed for other apartments.

However, since the study was comparative and all buildings were treated in a similar manner, it was considered unnecessary to refine the analysis further.

The results for 1 to 10 occupants were dominated by smoke spread through open doors with the differences between the timber buildings and control buildings being largely attributable to the provision of fire sprinklers.

The higher consequence loss scenarios (10–100 occupants) were strongly linked to global collapse, which was more likely to occur with the steel frame and timber frame construction because of the lower inherent fire resistance compared to massive timber. Reliance on the inherent fire resistance is only needed when there is a gross defect with the primary fire protection system(s) and the sprinkler system (if provided) fails.

If defects are ignored, the Deemed-to-Satisfy fire resistance levels within the NCC were found to prevent global collapse if fire brigade intervention was taken into account for the three buildings. This is significant and highlights the importance of design of buildings with reasonable levels of structural redundancy, and appropriate quality controls with respect to passive fire protection system performance verification and installation/maintenance, which apply to all forms of construction. The analysis clearly demonstrated the ability of an additional primary fire protection system such as fire sprinklers to substantially mitigate these risks.

It is sometimes convenient to express outcomes in terms of a comparative risk to life based on the total estimates of occupants exposed to untenable conditions. These results are presented in Table 10.15 and the normalised results in Table 10.16.

Table 10.15: Expected risk to life results for Class 2 buildings.

	Control	Timber Frame	Massive Timber
Occupants exposed/annum – (expected risk to life) x 10^{-5}	54.2	4.9	3.3

Table 10.16: Normalised expected risk to life results for Class 2 buildings.

	Control	Timber Frame	Massive Timber
Normalised expected risk to life	1	0.091	0.061

Irrespective of the method of comparison the results indicate that the mid-rise timber buildings with automatic sprinkler protection provide a substantial improvement in safety of the occupants from potential flashover apartment fires compared to the non-combustible control building without automatic sprinkler fire protection.

10.9.2 Class 2 Building Fire-fighting Activities

An estimate of the impact on fire fighters can also be derived by construction of simple event trees as shown in Figure 10.21 and Figure 10.22.

The key factors are:

- The automatic fire sprinkler system would reduce the proportion of fully developed fires the fire fighters have to deal with.
- With the fire-protected timber systems required in the proposal for change (PFC), the probability of the timber structure becoming involved is reduced. If the timber structure is not involved, there will be no appreciable difference in the conditions facing the fire brigade.
- If the timber structure is ignited, the potential fire duration is increased and therefore there is a greater reliance placed on fire fighter activities.
- If there are cavities, additional fire-fighting measures may be required to locate the fire.

The percentage of potential flashover scenarios that may ignite timber members can be derived from the Monte Carlo analysis. The results for Level 7 of the generic building were 1% and 34% for the timber frame building and the massive timber building, respectively. This occurs because of the lower levels of protection permitted for massive timber compared to general timber construction.

Figure 10.21: Event tree for fire fighter outcomes – timber frame construction.

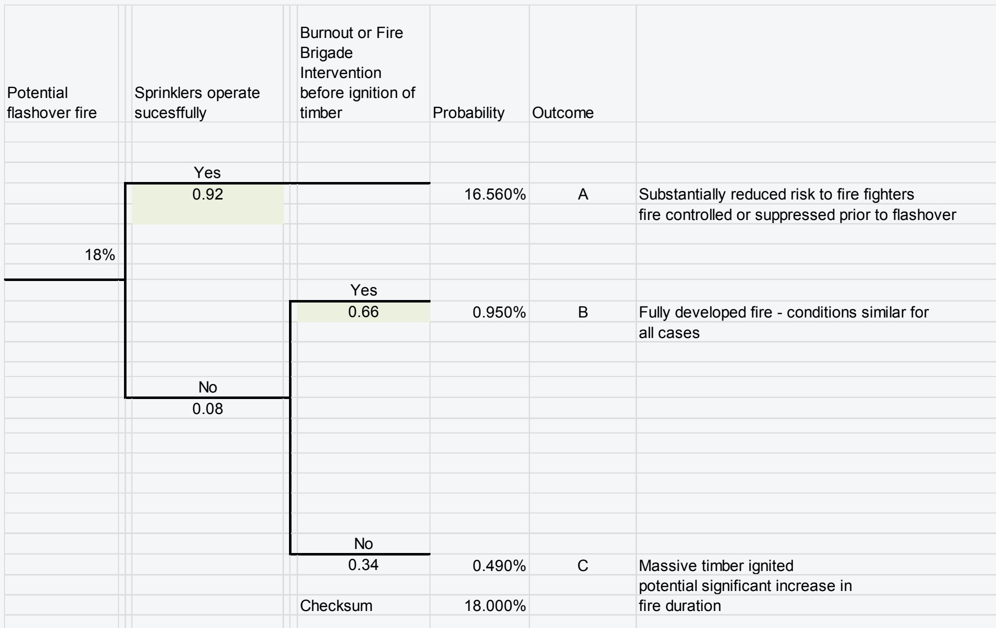


Figure 10.22: Event tree for fire fighter outcomes – massive timber construction.

For the control building, all potential flashover fire scenarios (18% of fires) would lead to outcome B – i.e. fire fighters having to deal with a fully developed fire. For the remaining non-flashover scenarios, the conditions facing fire fighters on arrival will be assumed to be similar for all the buildings (this is considered conservative since larger non-flashover fires may be controlled or suppressed by the automatic fire sprinklers.

Table 10.17: Impact on fire-fighting activities.

Outcome	Control	Timber frame	Massive Timber
A – Low Risk – no flashover	0%	16.56%	16.56%
B – Flashover -standard	18%	1.426%	0.95%
C – Additional actions required	0%	0.014%	0.49%

The additional actions required for timber-framed construction may comprise additional resources to address a potential increase in the fire duration and the need to ensure cavity fires are suppressed. Considering the very low probability of these scenarios (0.014%) and that there is an opportunity to call in additional resources, it is considered that there will be a large net improvement in the conditions faced by fire fighters with the timber-framed option in comparison to the control building.

The additional actions required for massive timber construction may comprise additional resources to address a potential increase in the fire duration. Considering the low probability of these scenarios (0.49%) and that there is an opportunity to call in additional resources, it is considered that there will be a large net improvement in the conditions faced by fire fighters with the massive timber option in comparison to the control building.

It is, however, necessary for fire fighters to develop procedures for fires in these types of buildings; in particular, methods to locate and suppress cavity fires.

10.9.3 Class 3 Building Occupant Safety Results

Based on the analysis of Class 2 buildings, it was determined that the analysis of fires occurring on Level 5 was sufficient to compare the relative performance of the three building types considered. The results expressed in a format that can be compared to F-N curves are shown in Table 10.18 (excluding the occupants of the apartment of fire origin).

For Class 3 buildings, an occupant group would vary between 1 and 6.5 people.

The occupants of Type 1 buildings have similar capabilities for self-evacuation to Class 2 building occupants; whereas, a larger proportion of Type 2 building occupants would require assistance to evacuate.

Table 10.18: Results expressed in an F-N format.

No of occupants exposed to potential untenable conditions	Frequency/annum x 10^{-6}		
	Control	Timber Frame	Massive Timber
Class 3 Type 1 1–3	21.66	1.74	1.71
Class 3 Type 1 4 or more	0.108	0.015	0.0008
Class 3 Type 2 1–3	27.13	2.16	1.94
Class 3 Type 2 4 or more	0.173	0.016	0.0017

Table 10.19 shows the results normalised to a building complying with current NCC DtS Provisions.

Table 10.19: Normalised expected risk to life results.

Outcome	Control	Timber frame	Massive Timber
Normalised Expected Risk to Life Class 3 Type 1	1	0.084	0.076
Normalised Expected Risk to Life Class 3 Type 2	1	0.082	0.064

The results show a large improvement in life safety, which is to be expected since a range of mitigation measures have been taken to minimise risks associated with timber structural elements, and automatic fire sprinklers have been additionally provided.

10.9.4 Class 3 Building Fire-fighting Activities

The impact on fire-fighting activities was considered and the results for the various buildings are summarised in Table 10.20.

Table 10.20: Estimated impact on fire-fighting activities Class 3.

Outcome	Control	Timber frame	Massive Timber
A – Low Risk – no flashover	0%	16.56%	16.56%
B – Flashover – standard	18%	1.437%	1.32%
C – Additional actions required	0%	0.003%	0.12%

For the control building, all potential flashover fire scenarios (18% of fires) will lead to outcome B – i.e. fire fighters having to deal with a fully developed fire. For the timber buildings, fewer than 1.5% of fires will reach flashover due to the provision of automatic fire sprinklers. Because of the required fire protection coverings, fire fighters are potentially going to be faced with additional actions required for timber-framed construction in only 0.003% of fires and 0.12% of fires for massive timber construction.

11

Fires in Paths of Travel

11.1 Fires in Paths of Travel – Fire Scenarios and Methods of Analysis

Sections 8 through to 10 considered the effect of fires starting in an SOU, which is the dominant location of fire starts. This Section considers fires starting in paths of travel.

From the analysis of fire incidents presented in Appendix F2, 3–4% of fires were estimated to occur in lobbies, entranceways, hallways and corridors in apartment buildings. These areas generally provide access to apartments and lie on the paths of travel to fire-isolated exits. While the frequency of these fires is relatively low, they have the potential to compromise the paths of travel from an apartment to a fire exit and also to cause rapid smoke spread to fire exits and other floors; depending upon the state of doors and other openings. Therefore, this low probability event may lead to high consequences, and further analysis was considered necessary to compare the proposed changes to the NCC 2016 with NCC 2015 Deemed-to-Satisfy (DTS) Provisions.

The most likely fire that has the potential to have a significant impact on fire-resisting elements was considered to be one involving upholstered furniture or similar materials that have a rapid fire growth rate. Such a fire has the potential to block access to an escape path for all occupants on the floor of fire origin if fire growth is not restricted and allows smoke spread to large areas of the remainder of the building, including fire-isolated stairs, before fire brigade Intervention.

Since the fire load in a public corridor or lobby is generally lower than within an SOU and wall and ceiling linings are controlled, the risk of flashover occurring in the corridor is low and, even if flashover occurs, the severity of a fully developed fire within the corridor would be likely to be much less than most fully developed apartment fires.

It therefore follows that the non-combustible fire-protective covering required to be applied to the fire-protected timber would mitigate the risk of the fire-protected timber becoming involved in a fire, and that the rate of fire growth and fire severity would be the same for the proposed timber buildings and a building satisfying the current NCC DTS requirements (if the impact of fire sprinklers is ignored).

The fire scenarios used to compare the building solutions were:

- A rapidly growing fire in a corridor filling the corridor on the floor of origin with smoke, potentially preventing the safe evacuation of occupants from the floor of fire origin.
- If the occupants try to evacuate through the smoke without assistance from the fire brigade, there is a significant probability that they will be exposed to untenable conditions. This probability of exposure is substantially reduced if automatic fire sprinklers operate effectively.
- If the occupants remain in their apartments with the door to the apartment closed, some smoke spread may occur to the apartment but fire and smoke separation will be consistent with the current NCC DTS provisions and will therefore be considered acceptable and to present an acceptable risk.
- If the door to an apartment is open, there is a significant probability that the occupants could be exposed to untenable conditions. This probability of exposure is substantially reduced if automatic fire sprinklers operate effectively. There is also a risk of fire spread to the apartment through the open door leading to flashover within that apartment, which would be prevented if automatic fire sprinklers operate successfully.
- If the door to the stair is open, there is a risk that smoke could spread to the stair potentially generating untenable conditions within or above the level of fire origin. Smoke spread may also occur via the lift shaft to upper level corridors, potentially exposing occupants on upper levels to smoke if they attempt to evacuate. This probability of exposure is substantially lower if automatic fire sprinklers operate effectively.

Although the qualitative discussion above indicated that the risks associated with fires in paths of travel to fire-isolated exits would be reduced for the fire-protected timber buildings due to the provision of automatic fire sprinkler system, a simple event tree analysis was also undertaken to provide some quantification.

Outcomes were estimated assuming rapid onset of untenable conditions in the corridor and in apartments with open doors prior to fire brigade intervention.

11.2 Fires in Paths of Travel – Acceptance Criteria

The fire-protected timber buildings with automatic fire sprinklers were considered to provide an acceptable level of protection against the corridor fire scenario, if the expected risk to occupants was less than the generic version of the building complying with the NCC DTS 2015 Provisions that require non-combustible construction.

11.3 Fires in Paths of Travel – Results and Assessment

The simple event trees used to analyse the potential outcomes from a fire occurring in a corridor are shown in Figure 11.1 and Figure 11.2 for scenarios with and without sprinkler activation, respectively. Details for the inputs for both event trees are summarised in Table 11.1.

Table 11.1: Inputs for event tree analysis.

Event	Sprinklers		Comments
	None	Effective	
Occupants try to evacuate apartments on floor of fire origin	0.1	0.1	Most occupants would see smoke and sense heat and decide not to evacuate
Evacuating occupants return to apartment due to smoke/fire	0.95	0.95	Since conditions are severe most occupants return to apartment
Evacuating occupants exposed to untenable conditions in exit paths	0.5	0.1	Assumed 50% would evacuate past the smoke safely for no sprinkler and 90% if sprinklers activate (less hazardous conditions)
Doors to apartments closed	0.95 (0.9)	0.95 (0.9)	Reduced probability of doors in brackets applied if doors have been used in the emergency and if the automatic closers are not operational may be left open.
Occupants exposed to untenable conditions in apartment if door open	0.25	0	Fire sprinklers would be expected to prevent untenable conditions occurring in an adjacent enclosure

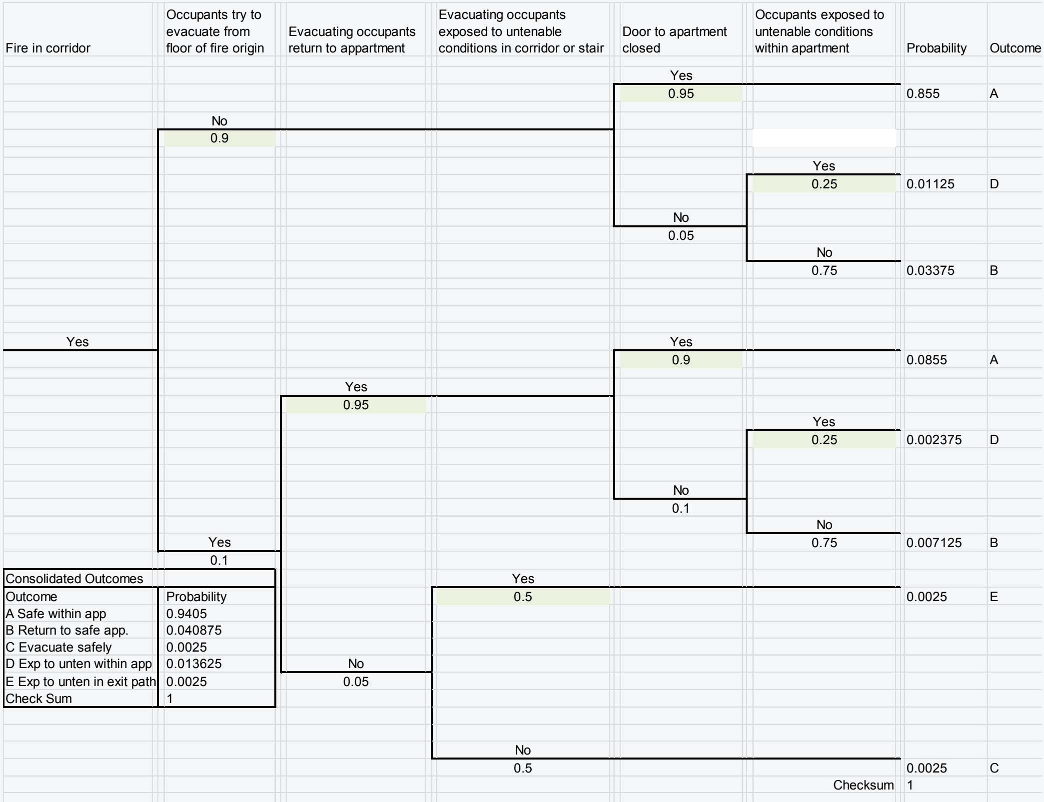


Figure 11.1 Event tree for corridor fire – no automatic suppression.

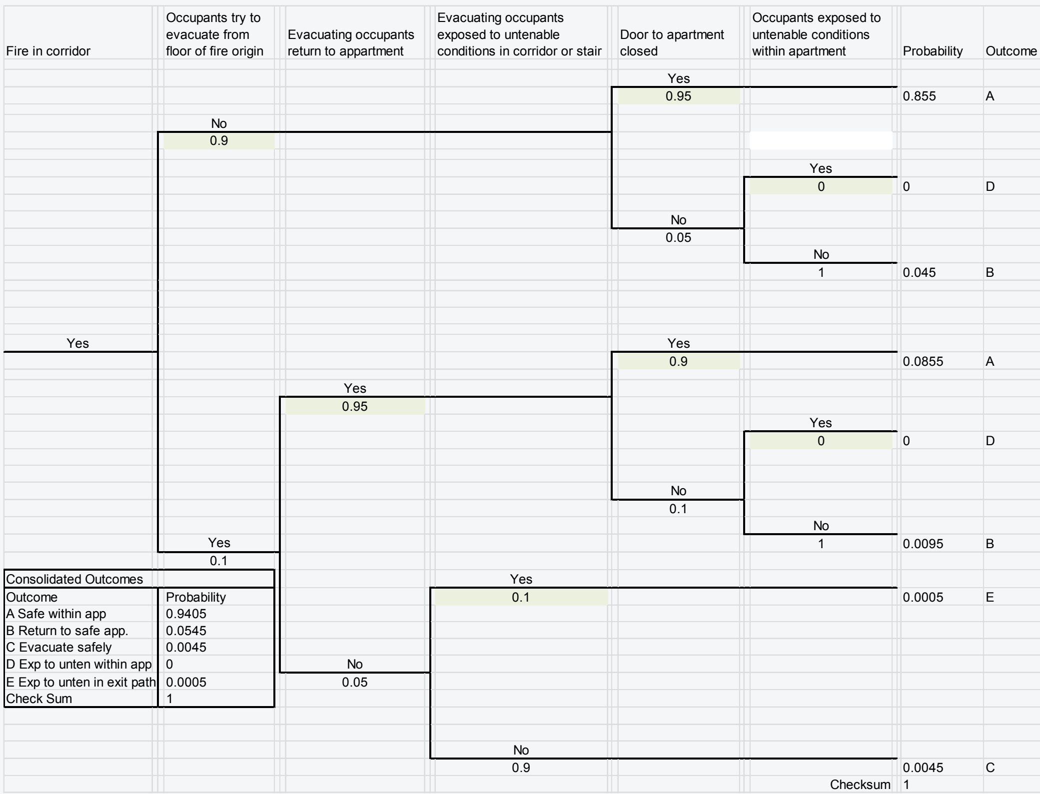


Figure 11.2: Event tree for corridor fire with automatic fire sprinkler suppression.

Allowing for six apartments on the fire floor and an average of 2.5 occupants/apartment (Class 2 and Class 3 Type 1) at the time of fire, the following outcomes were predicted:

- No sprinkler operation: (0.0136 + 0.0025) x 15 = 0.24 people potentially exposed to untenable conditions/fire
- Successful sprinkler operation: (0.0005) x 15 = 0.0075 people potentially exposed to untenable conditions/fire.

If a sprinkler effectiveness of 0.92 is assumed, the outcomes for the fire-protected timber buildings (including automatic fire sprinklers) can be calculated to be:

- (0.08 x 0.24)+(0.92 x 0.0075) = 0.026 people exposed to untenable conditions/fire compared to 0.24 people exposed to untenable conditions/fire for a building meeting the current NCC DTS Provisions.

Normalising the results such that the expected risk to life for this scenario is 1 for the Deemed-to-Satisfy Provisions yields the following:

- Normalised expected risk to life for the control building 1
- Normalised expected risk to life for the fire-protected timber buildings 0.11.

A large improvement in life safety was indicated, confirming the qualitative analysis findings and satisfying the acceptance criteria.

12

Fire in a Fire-isolated Stair

12.1 Fire in a Fire-isolated Stair and Passageway – Data

12.1.1 Proportion of Fires Occurring in Fire-isolated Stairs

From the analysis of fire incidents presented in Appendix F2, 0.1% of fires occur in fire-isolated escape routes and 0.8% occur within interior stairways. Since some fires occurring in fire-isolated escape routes were reported as occurring in interior stairways, it was assumed that between 0.1 and 0.9% of fires occur in fire-isolated stairs of passageways. While the frequency of these fires is low, as is the fire load, it may represent the only exit path for occupants and access path for fire fighters.

12.1.2 TF2000 Stair Fire Test

Overview of TF2000 Stair Fire Test

The analysis was based predominantly on experimental data reported in the DETR Framework Closing Report TF2000 Stair Fire Test[29].

As part of the TF2000 project in the UK, a series of stair fire tests were undertaken to facilitate the extension and harmonization of the UK regulations with respect to fire stairs in mid-rise timber buildings[29]. These tests have direct relevance to the Proposal for Change considered in this report.

The study identified the following fundamental consideration for a stair:

"The stair has to remain useable for fire fighting after initial evacuation of occupants immediately at risk and for subsequent evacuation by the other occupants of the flats who are initially advised to remain in their dwellings."

The above was used to provide guidance in addition to the relevant performance requirements in the NCC.

TF2000 Stair Construction

The TF 2000 fire stair wall/ceiling construction was required to achieve a fire resistance of 60 minutes, which was achieved by applying two 12.5 mm thick layers of standard-grade plasterboard to timber studs.

Within the stair enclosure, the stairway was constructed from fire retardant-treated softwood with fire retardant-treated timber balustrades using a thermosetting adhesive (Urea Formaldehyde).

The stairs were underdrawn with a single layer of standard-grade plasterboard 12.5 mm thick, fixed using clout nails at 150 mm centres to the stringers of the stair only.

Derivation of Acceptance Criteria and Fire Exposure Conditions

The TF2000 project identified the most onerous fire scenario as a fire that starts and grows in the stair due to materials being left or stored in the stairwell that are either accidentally or purposefully ignited.

While materials should not be stored in fire-isolated stairs and passageways, fires involving combustible materials introduced to fire-isolated stairs and passageways do occur (estimated to be between 0.1 and 0.9% of all fires based on the statistics presented in Appendix F2).

Therefore the scenario proposed for the TF2000 project was also considered to represent a credible severe scenario for comparison of the changes for mid-rise timber buildings introduced in the NCC 2016 edition against the NCC 2015 Deemed-to-Satisfy Provisions.

It was acknowledged that a significant fire within a fire-isolated stair could result in the development of untenable conditions irrespective of the form of construction used for the stair enclosure or stairway.

The following acceptance criteria were therefore adopted as the basis for evaluating the changes introduced into the NCC 2016 when exposed to a fire scenario developed by the TF2000 fire group:

- tenable conditions within the stair should be maintained for at least the same duration as the control building
- the stairway should remain serviceable for fire fighters throughout the fire emergency
- fire spread from the stair should be prevented to the same extent as the control building
- the fire-protected timber should not be ignited.

The TF2000 fire scenario included the following items ignited simultaneously:

- a double mattress held in the vertical position by tying to a balustrade on the ground floor
- a 500 mm x 500 mm 16 stick crib with stick size 50 mm x 50 mm mounted underneath the stair
- paraffin-soaked fire strips at the junction between the treads and risers on the first 5 steps.

Summary of TF2000 test results

Key outcomes of the test were:

- The test was practically completed 31 minutes after ignition after complete burnout of the mattress and the timber crib had reduced to glowing embers. The fire was allowed to burnout without suppression.
- Maximum general air temperatures within the stair shaft did not exceed 300°C (timber crib was fitted below the stair and it exposed the underside of the stair to a severe fire but the impact was localised.
- The void between the single 12.5 mm sheet of plasterboard and the underside of the stair directly above the timber crib reached approximately 120°C at the end of the test and the board remained in place indicating that the underside of the stair was adequately protected.
- The void between the single 12.5 mm sheet of plasterboard and the underside of the stair on the first floor above the mattress reached approximately 80°C at the end of the test.
- The stairs could support fire fighters gaining access to the upper levels after the fire.
- Untenable conditions were reached in the stair after approximately 6 minutes with the first fire detectors in the shaft operating after 4 minutes 21 seconds. It was therefore concluded that there was insufficient time for the occupants to evacuate via the stair. Since the contribution from the fire retardant stairs was minimal the same result would occur if the stair and stairway was of non-combustible construction.
- Closed doors to the stair (without smoke seals) prevented untenable conditions being reached on the upper levels.
- The fire did not spread from the stair enclosure.

12.2 Fire in a Fire-isolated Stair and Passageway – Assessment of Performance of Fire-protected Timber Construction

12.2.1 Fire Protection Lining System – General Timber Construction

The Deemed-to-Satisfy requirements for fire-isolated stairs or passageways of timber construction introduced into the NCC 2016 edition require the use of fire-protected timber (i.e. in Class 2 and 3 buildings the walls are required to achieve fire resistance levels of 90/90/90 or -/90/90 as appropriate and the fire protection lining system is required to prevent the interface temperature between the plasterboard and timber reaching 250°C for at least 45 minutes among other things when subjected to a fire resistance test). To achieve this level of performance the fire protection lining system requires a higher level of performance than the 60 minute fire resistance system selected for the TF2000 series.

The NCC 2016 Deemed-to Satisfy requirements for general timber construction relating to fire-isolated stair and passageway shafts were considered to satisfy the acceptance criteria derived in Section 12.1.2 as explained below:

- tenable conditions within the stair will be maintained for at least the same duration as the control building since the protected timber will not be involved in the fire
- the stairway should remain serviceable for fire fighters throughout the fire emergency – same conditions for the control and the fire-protected timber-framed construction

- fire spread from the stair should be prevented to the same extent as the control building – no difference since fire-protected timber would be expected to prevent fire spread (higher FRL required than TF2000 test and additional control assessed as per the following dot point)
- the fire-protected timber should not be ignited – achieved since no ignition occurred in the TF2000 test and fire protection lining system required for fire-protected timber has a higher level of performance.

12.2.2 Fire Protection Lining System – Massive Timber Construction

The Deemed-to-Satisfy requirements for fire-isolated stairs or passageways of massive timber construction that satisfies the requirements permitting the concession to apply, introduced into the NCC 2016 edition also require the use of fire-protected timber. However while an FRL of 90/90/90 or -90/90 is still required, the interface temperature limit between the plasterboard and timber is relaxed to 300°C for at least 20 minutes when subjected to the standard fire resistance test. To achieve this level of performance the wall system will require a higher level of performance than the 60 minute fire resistance system selected for the TF2000 series in terms of fire resistance. The massive timber interface temperature will rise more rapidly than the two layers of 13 mm fire-grade plasterboard and potentially faster than two layers of 12.5 mm thick standard plasterboard used in the TF2000 test depending upon the fixing detail.

However since a single layer of standard plasterboard 12.5 mm thick fitted to the underside of the stair in the TF2000 tests limited cavity temperatures to approximately 120°C directly above the timber crib it is considered unlikely that the fire scenario would generate sufficient heat to penetrate a fire protection lining system having the performance required in NCC 2016 for massive timber fire-protected members (e.g. a single layer of 13 mm fire-grade plasterboard).

The NCC 2016 Deemed-to Satisfy requirements for massive timber construction relating to fire-isolated stair and passageway shafts were considered to satisfy the acceptance criteria as explained below:

- tenable conditions within the stair will be maintained for at least the same duration as the control building since the protected timber will not be involved in the fire
- the stairway should remain serviceable for fire fighters throughout the fire emergency – same conditions for the control and the fire-protected timber construction
- fire spread from the stair should be prevented to the same extent as the control building – no difference since fire-protected timber would be expected to prevent fire spread (higher FRL required than TF2000 test and additional control assessed as per the following dot point)
- the fire-protected timber should not be ignited – achieved since no ignition occurred in the TF2000 test directly above the crib with a timber stair protected by a single layer of non-fire-grade plasterboard.

12.3 Timber Stairway Concession

12.3.1 Timber Stairway Concession – Background

An additional variation from the current NCC Deemed-to-Satisfy Provisions was evaluated to allow the use of timber stairways and ramps subject to the extension of automatic fire sprinkler coverage to include the stairs and passageway and the underside of stairs being protected by a single layer of 13 mm fire-protective-grade plasterboard or equivalent.

The concession is included in Clause D2.25 of the NCC 2016, which is summarised below:

(a) Notwithstanding D2.2(a) timber treads, risers. landings and associated supporting framework

which

(i) has a finished thickness of not less than 44 mm and

(ii) has an average density of not less than 800 kg/m^2 at a moisture content of 12%

may be used within a required fire-isolated stairway or fire isolated passageway constructed from fire-protected timber in accordance with C1.13 subject to –

(iii) the building being protected throughout by a sprinkler system complying with Specification E1.5 which extends to within the fire isolated enclosure and

(iv) fire protection being provided to the underside of stair flights and landings located immediately above a landing level which –

(A) is at or near the level of egress; or
(B) provides direct access to a carpark

(b) Fire protection required by (a) must be not less than one layer of 13 mm fire-protective-grade plasterboard fixed in accordance with the system requirements for a fire-protective covering.

12.3.2 Assessment of Performance of Timber Stairway

The TF2000 test series focused on the use of fire retardant-treated timber stairways with supplementary materials controls and protection of the underside of the stairways to satisfy the acceptance criteria. A successful fire test was undertaken with this configuration.

The NCC Clause D2.23 Timber Stairway Concession extends coverage of the fire sprinklers to the fire stairs in lieu of requiring fire retardant-treated timber, and additional controls were added requiring the exposed timber to have a finished thickness of not less than 44 mm and an average density of not less than 800 kg/m^2 at a moisture content of 12%.

A number of initial trials were undertaken as part of the TF 2000 series. The first trial was undertaken using untreated stairway components and included three test runs. This data is therefore directly relevant to the changes to the NCC introduced in the 2016 edition.

The first run of trial one was undertaken with a double mattress tied to the balustrades, and a porous fibre board soaked in paraffin was placed on the first step of the lower flight. Complete combustion of the mattress took place. The spindles and handrail of the baluster were involved in the fire causing extensive charring; however, no damage was inflicted on the stair treads and risers and only very limited charring of the vertical face of the lower stringer was observed.

The second run was an attempt to initiate a 'trench' effect by placing paraffin-soaked fibre strips at the junctions between the treads and risers of the first five steps on the lower flight. Ignition of the strips was reported to have led to a short period of sustained burning where the flames were observed 'lying down' and surface charring to a depth of 2–3 mm of the first five steps was the result. The fire died out as the strips and paraffin were consumed and there was no further spread of flame. The structural integrity of the stairs was maintained and verified by personnel walking on the treads.

The third run involved removing the plasterboard from the underside of the stairs and placing a timber crib (16 sticks of 50 x 50 x 500 mm softwood) underneath the lower surface of the first flight. This fire led to a breakthrough of the fire on the stairs and the stringer after 10 minutes with the lower flight becoming fully involved in the fire, and the fire was suppressed.

The second trial was similar to the first trial except that the timber members were treated with fire retardant. The fire retardant treatment reduced the fire spread from that observed in trial one, particularly with the timber crib configuration. However, after the crib test, a number of treads directly above the crib were damaged to the extent that they broke from the stringers when they were stepped on. The use of a PVA adhesive was considered to have contributed to the failure and Urea Formaldehyde adhesives were used in trial 3 and the full test.

In the full test, the plasterboard protection to the underside of the stairs was left in place and prevented the temperature from exceeding 120°C in the cavity, and was intact at the end of the test. In trial 3, the same configuration was tested and the lining fell away at the end of the test but ignition of the underside of the stair did not occur.

If fire-grade plasterboard had been used in lieu of standard plasterboard, the risk of the board falling away would be substantially reduced. Under such circumstances, it is likely that the board would prevent ignition of the underside of the steps, irrespective of whether the timber is fire retardant-treated or not, and the stair assembly from trial one would have been likely to achieve performance consistent with the acceptance criteria.

It therefore follows that for the TF2000 solution, the fire retardant treatment would reduce the extent of fire damage to the exposed timber elements and provide some redundancy if the lining failed.

The NCC 2016 requires a higher specification for the lining protecting the underside of the stair and additional fire sprinkler protections. Since temperatures approaching 300°C were achieved within the main stair, and higher temperatures directly under the stair, these temperatures would be sufficient to activate a sprinkler head reducing the size of the fire and hence reducing reliance on the fire protection lining system. In some instances, tenability may be enhanced, but this will depend upon the nature of the fire source and proximity to the head.

It was therefore considered that the NCC stairway concession satisfies the proposed acceptance criteria as explained below:

- Tenable conditions within the stair will be maintained for a similar duration to the control building since the contribution from exposed timber members will be minimal. While visibility may be temporarily reduced upon activation of the sprinklers, temperatures within the stair will be reduced and the net effect would tend to be neutral or improved tenability conditions for most scenarios.
- The stairway should remain serviceable for fire fighters throughout the fire emergency – generally similar conditions expected.
- Fire spread from the stair should be prevented to the same extent as the control building – an improvement is expected because of the potential for early suppression by the automatic fire sprinkler.
- The fire-protected timber should not be ignited – achieved since no ignition occurred in the TF2000 test directly above the fire with a timber stair protected by a single layer of non-fire-grade plasterboard. The sprinkler system provides an additional redundancy.

13

Fire in Lift Shafts

13.1 Lift Shaft Fire Scenarios and Frequency of Fire Starts

From the analysis of fire incidents presented in Appendix F2, 0.22% of fires occur in lift /dumbwaiter shafts.

Assuming the frequency of fires for the subject building is approximately 42 x 10^{-3} fires /annum, the frequency of fire starts in the lift/dumbwaiters shaft would therefore be approximately 9.2 x 10^{-5} fires / annum.

Since the fire load is small and lining materials within the lift cars are required to achieve either Group 1 or Group 2 performance, it will be assumed that only 5% of these fires grow to be significant fires (i.e. 4.6 x 10^{-6} fires/annum). This is comparable to an estimate of 2.86 x 10^{-6} fires/annum/per lift car made by Bennetts et al.[30]. For the purposes of this analysis, a value of 5 x 10^{-6} fires/annum will be adopted for significant fires, which would be expected to be conservative for buildings with a single lift such as the generic building considered in the comparative analysis of the fire-protected building options.

The following major groups of fire scenarios have been identified:

- fires starting within the shaft
- fires adjacent to the shaft exposing the lift landing doors
- fires occurring within a combustible lift car.

13.1.1 Fire Starts within Lift Shafts

Due to the limited volumes of combustible materials within lift shafts, fires within a lift shaft are expected to be small and typically involve small amounts of debris. It is therefore considered that the fire protection coverings for fire-protected timber verified for fire-isolated stairs can be conservatively applied to this scenario and no further analysis is required.

13.1.2 Fires in Lift Lobby Areas

Bennetts et al[43] undertook fire tests to determine conditions within the lift shaft when a fully developed fire occurs in the adjacent lift lobby. The tests were performed with a plasterboard shaft and temperatures were measured on the plasterboard wall directly opposite the lift landing doors exposed to a fully developed fire. The temperatures peaked below 200°C which would not cause ignition of the protected timber. For the timber buildings, automatic fire sprinkler systems are provided substantially reducing the probability of this scenario occurring. No further analysis is therefore required for this scenario

13.1.3 Fires in the Lift Car

Due to the requirement for Group 1 or Group 2 linings for the lift car, a large ignition source would be required which would be more likely to be malicious rather than accidental. Bennetts et al.[30] identified scenarios where such fires could achieve flashover within the lift car that would burn through the lift car structure and threaten the shaft and structures within it, while acknowledging that such events would be very rare.

Based on full-scale experiments, a design fire exposure of 850°C for 25 minutes for the evaluation of steel structural elements was recommended. This exposure has been adopted for evaluation of the fire-protected timber shafts.

The enclosure/fully developed fire model used for the evaluation of apartment fires was adapted by inputting the above design fire rather than using the apartment dimensions and fire load to generate a series of exposures.

The NCC generally requires the fire-protective linings for fire-protected timber to prevent interface temperatures exceeding 250°C for 45 minutes equivalent fire resistance period. A standard deviation of 10% (4.5 minutes) was assumed for the model.

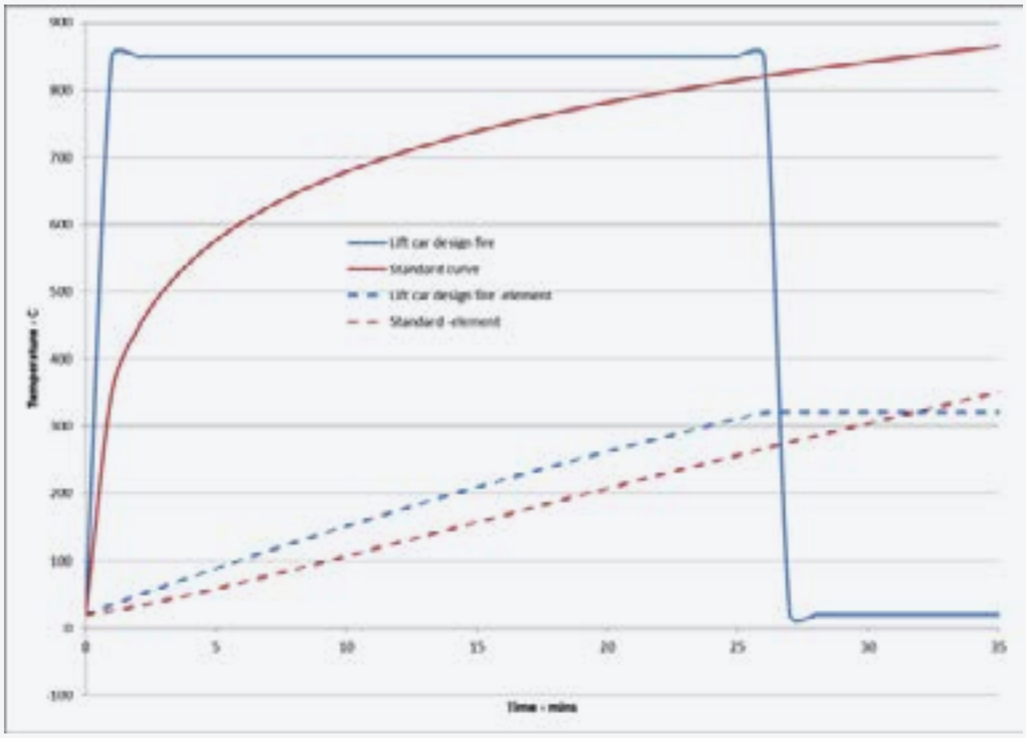


Figure 13.1: Lift car design fire and standard heating regime.

The design fire exposure was equivalent to about 32 minutes fire resistance period as shown in Figure 13.1.

Fire brigade intervention was based on the estimates for a fire on the top floor (slowest response).

The modelling indicated that the fire would burnout before the interface temperature exceeded 250°C without fire brigade intervention in 99.8% of scenarios, and that in the majority of the remaining 0.2% of scenarios fire brigade intervention would be likely to occur before the temperatures of the timber interface exceed 250°C. In an extremely small proportion of scenarios (approx. 2.8×10^{-4}), fire brigade intervention occurs marginally after the 250°C interface temperature is exceeded. As this equates to a frequency of 1.4×10^{-9} fires/annum, and the timber frame shaft wall is required to achieve a fire resistance of 90 minutes, it is considered that the timber frame NCC 2016 requirements provide adequate protection against this scenario with outcomes similar to the control building.

For massive timber, the NCC Deemed-to-Satisfy Provisions require fire protection linings within lift shafts to prevent the interface temperature reaching 300°C for 20 minutes. A standard deviation of 10% (2 minutes) was assumed for the model and fire brigade intervention was based on the estimates for a fire on the top floor (slowest response).

Due to the lesser level of protection, the timber substrate would exceed 300˚C in most cases unless fire brigade intervention occurred before the temperature limit was exceeded. Fire brigade intervention has been estimated to occur prior to the 300°C temperature limit being exceeded in approximately 6.1% of scenarios with ignition expected in the remaining scenarios as shown in Figure 13.2. However, full burnout of the lift car would occur prior to failure of the massive timber walls, which are required to achieve an FRL of 90/90/90 minutes and also have a high inherent fire resistance making them less susceptible to gross defects.

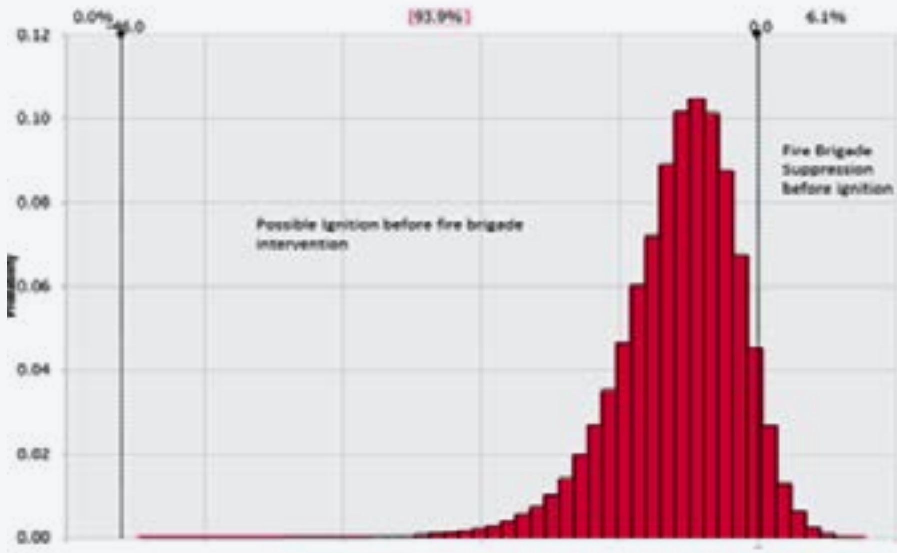


Figure 13.2: Fire brigade intervention outcomes (limit time – fire brigade intervention time) – massive timber.

The consequences of a fully developed fire occurring in the lift car (low frequency – estimated at less than 5×10^{-6} fires/annum) would tend to be localised with damage to the fire protection linings and possible ignition of the massive timber substrate being restricted to the area around the lift car. Since the remainder of the linings are likely to remain in place the fire would be unlikely to spread throughout the lift shaft and would be expected to be supressed by the fire brigade with smoke spread to the remainder of the building being similar to an equivalent fire in a building of non-combustible construction. It was therefore considered that the massive timber requirements provide adequate protection against this scenario with outcomes similar to the control building for mid-rise sprinkler protected buildings.

13.2 Lift Shaft Fire Conclusions

The coverings required for fire-protected timber applicable to general timber construction were found to be likely to prevent ignition of the timber substrate in the rare event of a fire in a lift shaft or lift car.

The coverings required for fire-protected timber in massive timber construction were found to be likely to prevent ignition of the timber substrate for most lift shaft fires, except for a fully developed fire in a lift car (which is a very rare event). The level of damage under these circumstances was expected to be localised and the additional risk exposure to occupants is considered low. Having regard for the low frequency of these fires and expected consequences, this level of damage was considered acceptable.

14

Fires in Concealed Spaces

14.1 Concealed Space Fires – Background

Cavities within fire-resisting construction can provide paths for the spread of fire that can bypass the boundaries of a fire-resisting compartment, potentially compromising a fire safety strategy. Spread through cavities can be accelerated by the presence of combustible materials and linings within the cavities.

Prior to the 2016 edition, the NCC addressed this risk, where considered appropriate, by requiring ceiling membranes to be resistant to the incipient spread of fire in accordance with Clause A2.5 of the NCC where there are unprotected cavities connecting fire compartments.

Resistance to the incipient spread of fire is defined as follows in the NCC:

"Resistance to the incipient spread of fire, in relation to a ceiling membrane, means the ability of the membrane to insulate the space between the ceiling and a roof or ceiling and a floor above so as to limit the temperature rise of materials in this space to a level that will not permit the rapid and general spread of fire throughout the space."

Clause A2.5 of the NCC requires the resistance to the incipient spread of fire to be determined by submitting a prototype to the Standard Fire Test (AS 1530.4), which applies a temperature rise criteria of 250°C to the upper face of the ceiling membrane.

In other countries, such as the UK, a different approach is adopted whereby cavity barriers are specified to close off openings that potentially breach fire compartments within concealed cavities.

The NCC 2016 adopted a combination of these approaches to provide a robust solution in addition to requiring automatic fire sprinkler protection.

14.2 Concealed Space – Fire Scenarios

There are two main fire scenarios to consider for fire-protected timber elements:

- Flashover fires with sufficient intensity to penetrate the fire-protective linings and ignite the substrate. Once a timber element is ignited, fire can spread through the cavity – potentially bypassing fire compartment boundaries.
- Fires initiating within the cavities that ignite combustible materials and spread through the cavity – potentially bypassing fire compartment boundaries.

These risks associated with these scenarios are analysed in Appendix I.

14.3 Fire Spread to Cavity from Fully Developed Fire

With the NCC 2016 Deemed-to-Satisfy solution for mid-rise timber buildings in place, the estimated frequency of a potential fully developed fire spreading to cavities (spreading through the cavity past cavity barriers and breaking out into another fire compartment) was estimated to be approximately 1×10^{-6} fires /annum for the building being analysed.

If this occurs, the consequences are not expected to be severe as the onset of untenable conditions and structural damage would be expected to be slow, providing time for search and rescue and evacuation. If a major structural failure was to occur and if the building is designed to resist disproportionate collapse, the failure would expect to be localised.

The risk to occupants was therefore considered acceptably low with the combination of measures specified in the NCC 2016 edition.

14.4 Fires Initiating in Cavities

With the NCC 2016 Deemed-to-Satisfy solution for mid-rise timber buildings in place, the estimated frequency of a fire igniting within the cavity and not being suppressed during the early stages of a fire was estimated to be approximately 2×10^{-5} fires per annum.

The consequences are not expected to be severe if this occurs, due to the requirements for cavity barriers and controls applied to insulating materials. The fires would be expected to be suppressed prior to causing significant damage to adjacent apartments or other fire compartments and, even if the fire progressed unchecked, the onset of untenable conditions and structural damage would be expected to be slow, providing time for search and rescue and evacuation. If a major structural failure was to occur and if the building is designed to resist disproportionate collapse, the failure would be expect to be localised.

The risk to occupants was therefore considered to be acceptably low with the combination of measures specified in the NCC 2016 edition for mid-rise timber buildings.

15

External Fire Spread Building Façade

15.1 Fire Spread from a Fire within the Subject Building

This scenario comprises fire spread due to a flashover fire occurring within the building and spreading to the floor above via windows and other openings. This mode of fire spread can occur with non-combustible construction as well as combustible construction due to flames extending from the fire compartment which tend to adhere to the façade above the opening. If the flame extension is long enough and flame temperature high enough fire spread can occur to the level above, by-passing internal compartmentation. The existing NCC Deemed-to-Satisfy Provisions generally address this to some extent by means of vertical separation of openings in walls. The relevant NCC clause is stated below:

C2.6 Vertical separation of openings in external walls

(a) If in a building of Type A construction, any part of a window or other opening in an external wall is above another opening in the storey next below and its vertical projection falls no further than 450 mm outside the lower opening (measured horizontally), the openings must be separated by –

(i) a spandrel which –

(A) is not less than 900 mm in height; and

(B) extends not less than 600 mm above the upper surface of the intervening floor; and

(C) is of non-combustible material having an FRL of not less than 60/60/60; or

(ii) part of a curtain wall or panel wall that complies with (i); or

(iii) construction that complies with (i) behind a curtain wall or panel wall and has any gaps packed with a non-combustible material that will withstand thermal expansion and structural movement of the walling without the loss of seal against fire and smoke; or

(iv) a slab or other horizontal construction that –

(A) projects outwards from the external face of the wall not less than 1100 mm; and

(B) extends along the wall not less than 450 mm beyond the openings concerned; and

(C) is non-combustible and has an FRL of not less than 60/60/60.

(b) The requirements of (a) do not apply to –

(i) an open-deck car park; or

(ii) an open spectator stand; or

(iii) a building which has a sprinkler system complying with Specification E1.5 installed throughout; or

(iv) openings within the same stairway; or

(v) openings in external walls where the floor separating the storeys does not require an FRL with respect to integrity and insulation.

(c) For the purposes of C2.6, window or other opening means that part of the external wall of a building that does not have an FRL of 60/60/60 or greater.

The mid-rise timber buildings satisfy this clause through the provision of an automatic fire sprinkler system whereas the control building would comply with the options stated in clause C2.6 (a), for example a 900 mm high spandrel panel.

With the increased proportion of plastics making up fire loads in modern apartment buildings there is a trend for a greater proportion of fully developed fires to be highly ventilation controlled during the early post-flashover period until the smaller/less massive components that are easily volatised are consumed after which the fire will move towards stoichiometric conditions and finally fuel controlled conditions before entering a decay phase. Highly ventilation controlled fires can yield longer flame extensions from the fire compartment that can cause the separation distances specified in C2.6 to be ineffective. This is demonstrated in Table 15.1 taken from England and Eyre[31] which shows measurements of heat flux and temperature taken 1.5 m and 3 m above an opening in a full scale façade test. The exposure during the ventilation controlled phases would be expected to cause breakage of windows and subsequent fire spread at distances above the minimum 900 mm separation distance specified in NCC clause C2.6.

Table 15.1: Summary of key results from a Façade test during different stages of a fire taken from England P and Eyre M[44].

Test reference	Test time (minutes)	Burning regime	Enclosure Temp (°C)	Heat flux 1.5 m above opening (kW/m²)	Heat flux 3 m above opening (kW/m²)	Temp 1.5 m above opening (°C)	Temp 3.0 m above opening (°C)
Control	2	Growth (fuel controlled)	50	2	1	46	39
Balcony			67	1	1	53	24
Control	20	Strong vent controlled	813	104	43	1000	741
Balcony			831	67	15	639	461
Control	28	Vent controlled	1018	65	29	777	433
Balcony			1029	41	11	467	386
Control	35	Stoichiometric (approximate)	1090	30	18	636	417
Balcony			1088	13	5	312	313
Control	40	Decay phase (fuel controlled)	785	20	12	467	303
Balcony (removed)			763	17	5	420	262

In addition to the above, the fire-protective coverings required for fire-protected timber were shown in the previous sections to provide adequate protection of the timber elements and the coverings are required to be non-combustible, it was considered that the provision of automatic fire sprinklers in the proposed mid-rise buildings would be more effective than a 900 mm non-combustible spandrel panel. Therefore with respect to this mode of fire spread mid-rise timber buildings are considered to present a lower risk than the control building predominantly due to the provision of automatic fire sprinklers.

15.2 Ignition of the External Façade by Burning Materials/Equipment

Specification C1.1 of the NCC requires external walls to be non-combustible (Clauses 3.1(b) and 4.1(b)) for Type A and B construction and Clause C1.13 "Fire-protected timber: Concession" permits the use of fire-protected timber wherever an element is required to be non-combustible subject to certain conditions. This means that for mid-rise timber buildings, if fire-protected timber is used for external walls, non-combustible covering materials that will prevent ignition of the timber structural members for the equivalent fire resistance test periods of approximately 30 minutes for massive timber and 45 minutes for timber-framed construction must be used, among other things. One layer of 16 mm fire-grade plasterboard and two layers of 13 mm fire-grade plasterboard are Deemed-to-Satisfy these criteria respectively.

These coverings would therefore be expected to resist open fires on balconies and adjacent structures which would be expected to be less severe than an enclosure fire.

Further confidence can be derived by considering the typical fire sources that were developed as described in previous sections for materials introduced into fire-isolated passageways including a mattress and timber crib. Protection against ignition was demonstrated by a single layer of 12.5 mm standard-grade plasterboard located directly above the timber crib.

Ignition of the façade (including the underlying timber) is therefore considered unlikely prior to burnout of small/medium fire sources on balconies or adjacent to the buildings and the probability of such an occurrence would be similar to the control building with unprotected openings providing the greatest weakness.

It should be noted that any additional components such as weather resistant coverings and rain screening must still be non-combustible to comply with the NCC Deemed-to-Satisfy solutions since they form part of the external wall.

Fire spread from large ignition sources (i.e. adjacent structures) is considered in Section 16.

16

Fire Spread Between Buildings

16.1 Fire Spread from Fire-protected Timber Buildings

The risk of fire spread from the subject building to adjacent buildings is considered to be substantially less for the fire-protected timber buildings, compared to an NCC Deemed-to-Satisfy building, because the majority of potential fully developed fires will be suppressed prior to flashover.

For the small proportion of fires involving failure of an automatic fire sprinkler system, the fire severity for fire-protected timber buildings would be expected to be similar to a fire in a building complying with the requirements of the NCC 2015 edition for non-combustible construction, based on the analysis described in earlier sections of this Guide. It was therefore considered that no further analysis of this scenario was required.

16.2 Fire Spread From Adjacent Buildings and Allotments to Fire-protected Timber Buildings

16.2.1 Derivation of Acceptance Criteria for Fire Spread from Adjacent Structures or Allotments

The risk of fire spread to fire-protected timber buildings from adjacent buildings and allotments was assessed based on the radiation exposures nominated in Verification methods CV1 and CV2 of the NCC which state:

CV1

Compliance with CP2(a)(iii) to avoid the spread of fire between buildings on adjoining allotments is verified when it is calculated that—

(a) a building will not cause heat flux in excess of those set out in column 2 of Table CV1 at locations within the boundaries of an adjoining property set out in column 1 of Table CV1 where another building may be constructed; and

(b) when located at the distances from the allotment boundary set out in column 1 of Table CV1, a building is capable of withstanding the heat flux set out in column 2 of Table CV1 without ignition.

Table 16.1: Table CV1 from NCC 2015.

Column 1	Column 2
Location	**Heat Flux (kW/m²)**
On boundary	80
1 m from boundary	40
3 m from boundary	20
6 m from boundary	10

CV2

Compliance with CP2(a)(iii) to avoid the spread of fire between buildings on the same allotment is verified when it is calculated that a building—

(a) is capable of withstanding the heat flux set out in column 2 of Table CV2 without ignition; and

(b) will not cause heat flux in excess of those set out in column 2 of Table CV2, when the distance between the buildings is as set out in column 1 of Table CV2.

Note Refer to Section 16.1 for assessment of fire spread from fire-protected timber buildings

Table 16.2: Table CV2 from NCC 2015.

Column 1	Column 2
Distance between Buildings	**Heat Flux (kW/m²)**
0 m	80
2 m	40
6 m	20
12 m	10

From Table 16.1 and Table 16.2, the maximum radiant heat flux a building is required to resist at any distance from a boundary or adjacent building is 80kW/m² and the maximum radiant heat flux 1 m from a boundary or 2 m from an adjacent building on the same allotment is 40kW/m².

The duration of high intensity burning during a typical enclosure test lasts approximately 20–30 minutes as shown in Figure 16.1, which is taken from England and Eyre[31].

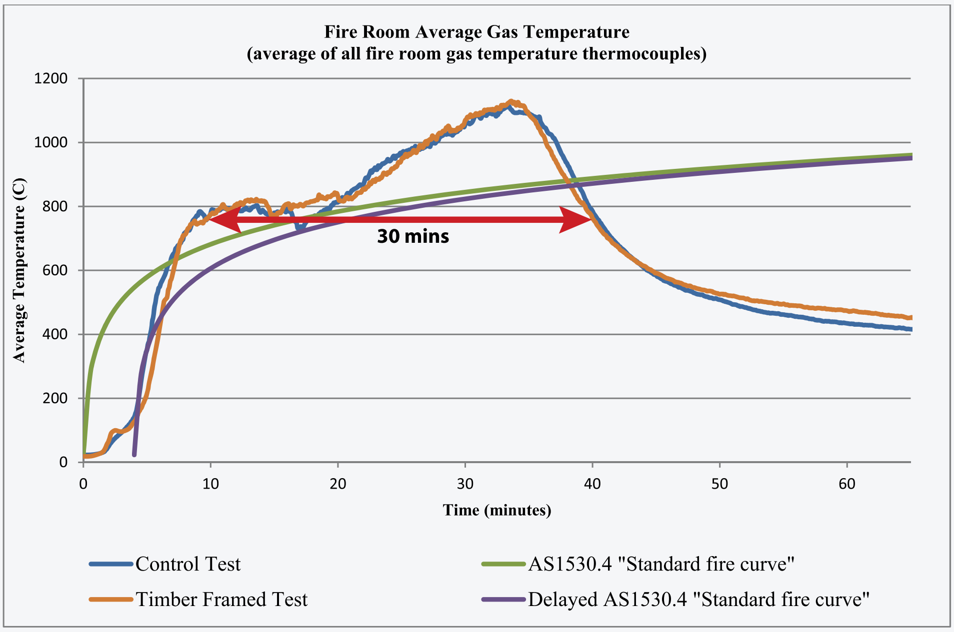


Figure 16.1: Typical fire scenario showing high enclosure temperatures for approximately 30 minutes.

Therefore the following acceptance criteria were adopted:

The temperature of the timber substrate of the Fire-protected Timber shall not exceed 300°C when

a) exposed to an incident radiant heat flux of 80kW/m² for 30 minutes for general application, or

b) exposed to an incident radiant heat flux of 40kW/m² for 30 minutes for buildings that are not less than 1m from the allotment boundary or 2m from an adjacent building on the same allotment.

16.2.2 Analysis of Fire Spread from Adjacent Structures or Allotments

Olsson[32] reported a series of cone calorimeter tests exposing timber specimens protected by plasterboard to radiant heat. Subsequently, Tsantaridis[33] also undertook a large series of cone calorimeter tests that incorporated a larger number of plasterboard-protected timber specimens. In both studies, the majority of the tests were undertaken with radiant heat fluxes of 50kW/m².

Tsantaridis fitted a 2nd order polynomial to the data based on a larger data set than that used for a linear correlation proposed by Olsson. The Tsantaridis correlation has been used for this study which is shown in Equation 1 and Figure 16.2 because of the larger data set and the 2nd order polynomial expression derived being more consistent with theory.

Equation 1 $T_{300} = 0.0796t^2 + 0.7144t$

where T_{300} is the time to 300°C – min, and t is the board thickness – mm

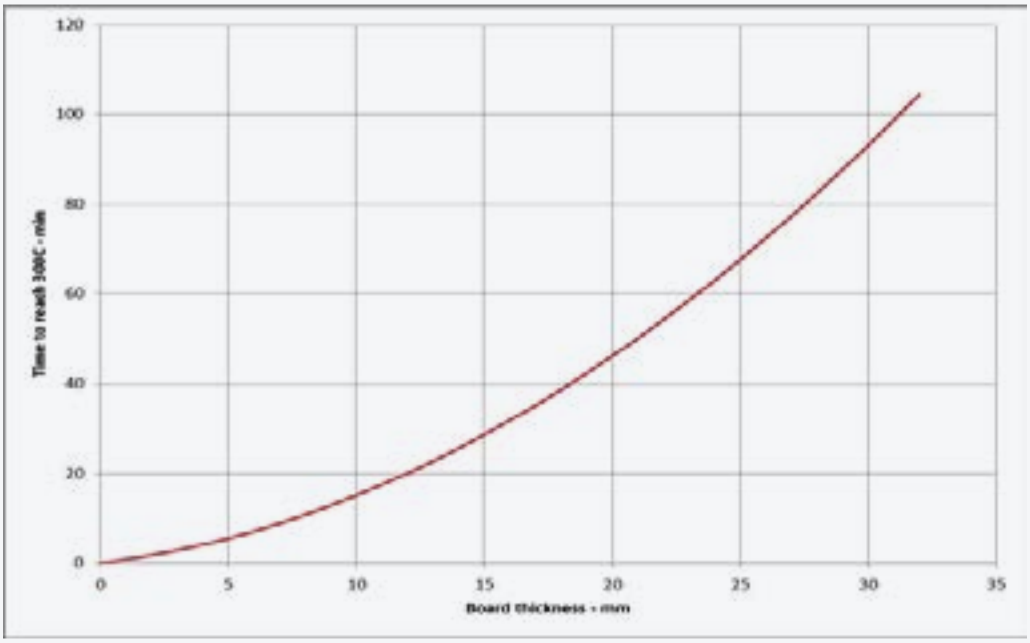


Figure 16.2: Time for timber interface temperature of 300°C when protected by differing plasterboard thicknesses and exposed to 50 kW/m² incident radiant heat flux based on Tsantaridis correlation.

It can be seen from Figure 16.2 that both massive timber and timber-framed construction protected by 16 mm and 26 mm plasterboard respectively would be expected to maintain interface temperatures below 300°C for more than 30 minutes, when exposed to a radiant heat flux of 50kW/m², therefore satisfying the criteria of 40kW/m² for buildings sited more than 1 m from the boundary and 2 m from other buildings on the same allotment.

Olsson reported results from timber elements protected by 12.5 mm plasterboard exposed to radiant heat fluxes varying from 25kW/m² to 100kW/m² which are plotted together with the time for the interface to attain 300°C in Figure 16.3.

From Figure 16.3, an incident radiant heat flux of 80kW/m² corresponds to the time for the timber interface to attain 300°C, of approximately 17.5 minutes.

Considering the form of the relationship between board thickness and time to attain an interface temperature, it is conservative to assume (i.e. under-predicts the time to reach a critical interface temperature) that doubling the board thickness will double the time for the interface to achieve a particular critical temperature when exposed to the same incident radiant heat flux, provided the boards remain in place.

Since two layers of 12.5 mm fire-grade plasterboard facings applied to timber studs have demonstrated their ability to remain in place for standard fire resistance tests of the order of 90 minutes, it is reasonable to assume they will remain in place when exposed to 80kW/m² for at least 30 minutes.

Therefore, two layers of 12.5 mm fire-grade plasterboard would be expected to prevent the interface temperature exceeding 300°C for in excess of 35 minutes when exposed to a radiant heat flux of 80kW/m², satisfying the criteria for buildings sited on the boundary and with 0 m clearance from other buildings on the same allotment.

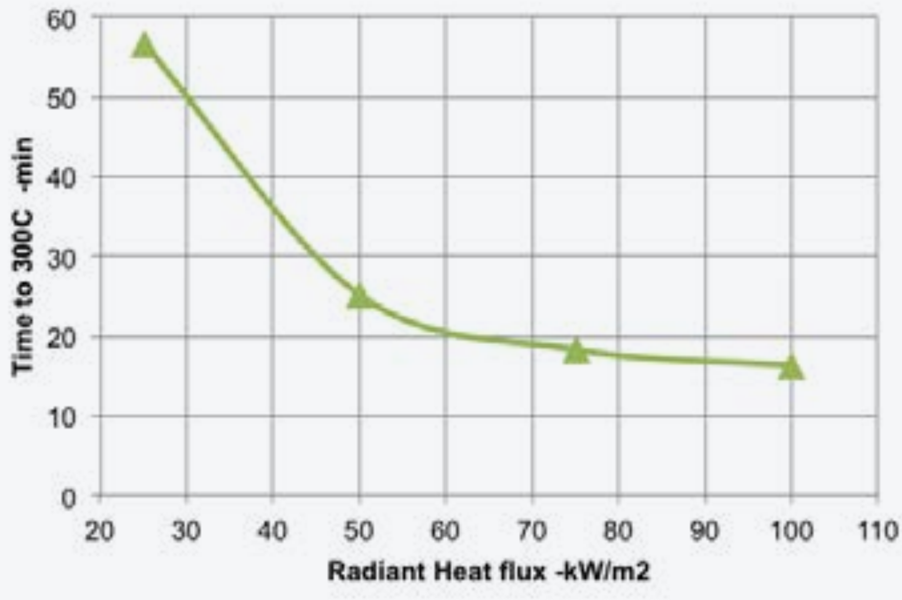


Figure 16.3: Time for timber interface temperature of 300°C when protected by 12.5 mm thick plasterboard and subjected to different radiant heat fluxes – Olsson results.

16.2.3 Results and Assessment of Fire Spread from Adjacent Structures or Allotments

For timber protected by the equivalent of two layers of 13 mm thick fire-grade plasterboard, the timber substrate of the fire-protected timber would not be expected to exceed 300°C when exposed to an incident radiant heat flux of 80kW/m^2 for 30 minutes, satisfying the acceptance criteria for all separation distances.

For timber protected by the equivalent of one layer of 16 mm thick fire-grade plasterboard, the timber substrate of the fire-protected timber would not be expected to exceed 300°C when exposed to an incident radiant heat flux of 40kW/m^2 for 30 minutes, satisfying the acceptance criteria for separation distances greater than 1 m from the boundary and 2 m from adjacent buildings on the same allotment.

The NCC 2016 Deemed-to-Satisfy requirements for fire-protected timber buildings are consistent with these findings, with the same levels of protection for massive timber and general timber construction of external walls being required within 1 m of the boundary or 2 m of adjacent buildings.

17 Application of Class 2 & 3 Findings to Class 5 Buildings

A supplementary analysis of Class 5 (office) buildings was undertaken, drawing heavily on the analysis undertaken for Class 2 and 3 buildings.

Further details of the supplementary analysis undertaken are provided in Appendix K: Class 5 Office Analysis and are summarised below:

A review of fire statistics indicates that Class 5 buildings present a much lower fire risk than Class 2 and 3 buildings, mainly due to the occupancy characteristics.

The analysis of fire incident data indicated that occupant safety would be significantly improved and fire losses reduced within the fire compartment of fire origin as a consequence of the provision of automatic fire sprinkler systems in the timber buildings, compared to the control building without fire sprinklers – as was the case with Class 2 and 3 buildings.

A supplementary analysis was undertaken to analyse the impact of a fully developed fire outside normal working hours. Since the building may unoccupied, the alarm to the fire brigade may not be received until substantially after flashover if the detection systems are unmonitored for the control building or the sprinkler system fails for the timber options.

Since the building would be likely to be unoccupied or have a very low occupancy rate at this time, it was decided that a simple event tree approach with point probabilities was appropriate, instead of the Monte Carlo approach used previously. Details are given in Appendix K4.3. The outcomes are summarised in Table 17.1.

Table 17.1: Event tree analysis of fully developed office fires.

Ref	Outcome	Probability of Outcome		
		Control Building	Massive Timber	Timber-framed
A	Sprinkler controlled	0	0.88	0.88
B	Fire brigade Intervention before ignition of structural element	0	0.1042	0.1130
C	Fire brigade intervention before equivalent FRL period	0.989961	0.012336	0.003504
D	Compartment withstands burnout without FBI	0.00894736	0.001622	0.002672
E	Fire spread without major collapse	0.00107984	0.001880	0.000830
F	Major structural collapse	0.000012	0.000002	0.000002

Outcome A relates to the successful activation of a sprinkler system. Approximately 88% of flashover fires would be expected to prevent in the timber buildings substantially reducing the fire losses and risk to any occupants outside normal working hours.

Outcome B applies only to the timber buildings. If the timber is not ignited the fire-fighting activities and risks would be similar to outcome C for the control building.

Outcome C relates to outcomes where the fire brigade suppress a fully developed fire prior to FRLs being exceeded. In this case the fire-fighting activities may be more complex for the timber buildings because the underlying timber elements may have ignited but the probability of occurrence for timber buildings is low.

Outcome D has the same consequence for all the buildings but the probability is less for the timber buildings, mainly because of the early suppression of most fires by the fire sprinkler systems. The value for massive timber is less than that for timber-framed construction because the fire preventative coverings provide protection for an equivalent of 30 minutes, compared to 45 minutes fire resistance for timber-framed construction.

Outcome E has the same consequence for all buildings but the probabilities vary. Due to the lower performance of the fire-protective coverings in conjunction with a delayed call to the fire brigade, the probability of this outcome is highest for massive timber construction. The lowest probability is for the timber-framed building, because of the higher level of performance required for the fire-protective coverings, which increases the proportion of fires that will burnout if there is no fire brigade intervention compared to the massive timber option.

Outcome F relates to a major structural collapse and the probability of occurrence is higher for the control and the same for the timber options.

Due to the provision of automatic fire sprinklers, fire fighters would face substantially fewer medium rise flashover fires, reducing the risk to fire fighters and minimising fire losses. However, in the rare event of failure of an automatic fire sprinkler system in conjunction with a severe flashover fire occurring and slower than average fire brigade response, there is a risk of the fire involving structural timber members and modified fire-fighting practices may be required.

It was determined that the analysis undertaken for Class 2 and 3 buildings relating to the following fire scenarios was applicable to Class 5 buildings:

- fires in fire-isolated stairs and passageways
- fire spread via the façade
- fire spread between buildings
- fires in lifts
- fire spread via concealed spaces.

Based on the above supplementary analysis, it was determined that:

- the acceptance criteria for the proposed timber mid-rise buildings was that the timber buildings should provide at least an equivalent level of fire safety to a building constructed in accordance with current NCC 2015 Deemed-to-Satisfy requirements. The analysis showed that this could be achieved with the NCC 2016 Deemed-to-Satisfy requirements for mid-rise timber buildings.

The Class 2 analysis indicated that although the risk of global collapse is very low, the frequency was dominated by the presence of gross defects and the inherent fire resistance of the base structural members. The additional analyses confirmed this applies also to Class 5 buildings, but the probability is increased outside normal working hours because fire brigade intervention times could be substantially delayed if there is no automatic alarm sent to the fire brigade, since there may also be no occupant or passer-by to manually call the fire brigade. The consequences with respect to life safety are, however, lower because the buildings are generally either unoccupied or have low levels of occupancy outside normal working hours.

D

Part D - Appendices

Appendix	Title
A	Response of Timber Buildings to Fires
B	Matters Raised by Stakeholders and Other Parties
C	Relevant Deemed-to-Satisfy Clauses NCC 2015
D	Performance Requirement Review
E	Determination of Compliance of Fire-protected Timber
F	Analysis of Fire Data
G	Multi-scenario Quantitative Risk Assessment Supplementary Data
H	Summary of UK Timber Frame 2000 Project – UK
I	Analysis of Fire Spread Via Concealed Spaces (Incipient Spread of Fire)
J	Comment on Structural Design Implications
K	Class 5 Office Analysis
L	Peer Review Letter
M	References

Appendix A - Response of Timber Buildings to Fires

A.1 Overview of Enclosure Fires

Figure A1 provides a general overview of the progression of a typical enclosure fire.

After ignition, a fire may spread to involve other items in the enclosure or self-extinguish, depending on many factors such as the ignition source; type of materials/objects first ignited; proximity to other objects and linings; and the material properties of the adjacent objects and linings.

The main focus of the NCC is on control of the fire properties of enclosure linings and elements of construction, rather than control of the building contents for residential and office buildings.

If a fire continues to grow it may be supressed or controlled by automatic systems, such as fire sprinkler systems if they are present, or manually by the occupants.

If these interventions do not occur or are unsuccessful and the fire continues to grow, it will tend to transition from a fire involving one or more items to a fully developed fire involving all exposed combustible materials within an enclosure. This transition is commonly referred to as flashover. Fire brigade intervention may occur prior to flashover or post-flashover, depending, among other things, on the call out time, response time and growth rate of the fire and may prevent flashover occurring in some instances or reduce the severity/duration of a fully developed fire.

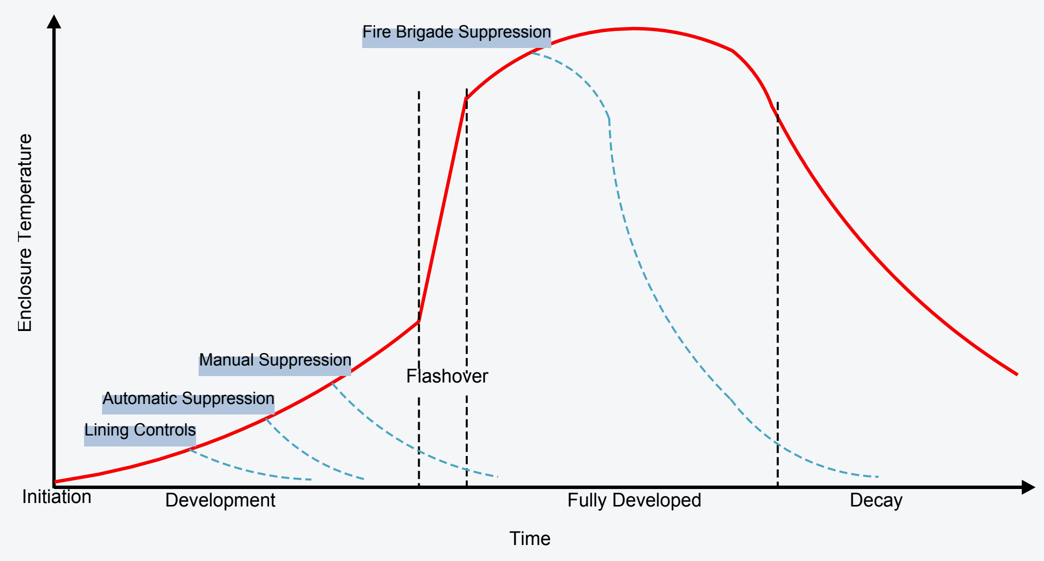


Figure A1: Enclosure fire stages.

Depending upon the ventilation conditions, amount of fuel and fuel characteristics, a fire may be fuel controlled or ventilation controlled. In many instances, a fully developed fire may initially be ventilation controlled immediately after flashover and transition to a fuel-controlled fire as the rate of production of volatiles reduces, as fuel packages with larger exposed surface area to mass ratios and low heats of gasification are consumed. The burning regime may impact on enclosure temperatures and flame extension from openings. A useful reference for further information is *An Introduction to Fire Dynamics* by D. Drysdale[34]. Maximum enclosure temperatures tend to occur when conditions are close to stoichiometric conditions (i.e. all fuel and air is consumed in the combustion process without any excess left over. If there is no intervention, the fire will eventually decay.

A.2 Overview of Degradation of Timber at Elevated Temperatures

When exposed to temperatures above 250°C to 300°C for relatively short periods (e.g. a fire event), timber will decompose – releasing volatiles – but it will also tend to form a char layer. This provides a degree of protection to the underlying timber, such that timber elements having a large cross section can exhibit high levels of inherent fire resistance.

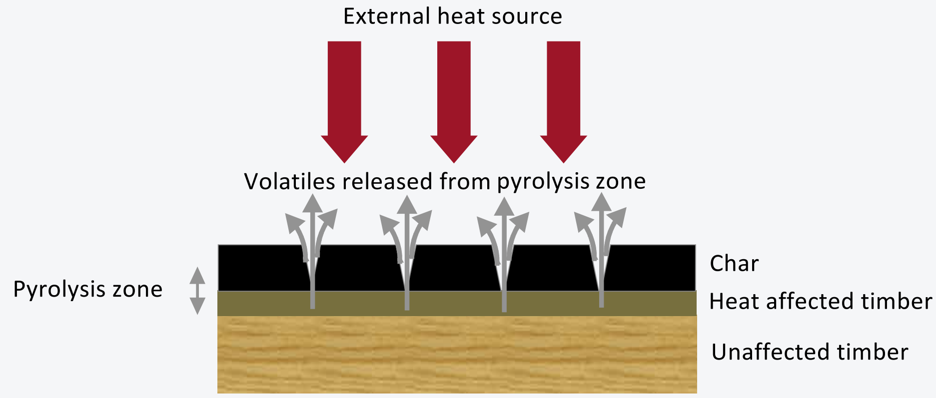


Figure A2: Schematic showing a section through a burning section of timber.

The rates of charring and production of volatiles depend on a number of variables. These include: timber species, cross-section, external heat flux, presence of inorganic impurities and moisture content; but for some engineering applications 'standard' design values are commonly adopted, such as those in AS 1720.4.

Adhesives and other fixings can also influence the response of engineered timber elements to elevated temperatures. For example, some types of adhesive can cause premature loss of the protective char layer, accelerating both the production of volatiles and char rate.

For a more detailed discussion of the burning behaviour of timber, refer to appropriate references such as Drysdale[34].

A.3 Summary of Fire-protected Timber Performance Criteria

Within the context of the NCC 2016, fire-protected timber is a defined term and compliance with Specification A1.1 is required. Specification A1.1 states that fire-protected timber is required to achieve the specified FRL of the building element, and have a non-combustible fire-protective covering applied to the timber which achieves a resistance to the incipient spread of fire (RISF) of not less than 45 minutes when tested in accordance with the relevant requirements of AS 1530.4.

AS 1530.4 applies a maximum temperature limit of 250°C for resistance to the incipient spread of fire. The NCC deems the 45 minute incipient spread of fire criteria to be satisfied if at least two layers of 13 mm thick, fire-protective-grade plasterboard are fixed in accordance with the requirements to achieve the required FRL for the element.

A relaxation is permitted for massive timber panels, provided the timber is at least 75 mm thick and there are no cavities between the surface of the timber and the fire-protective covering, or between timber members. If all these conditions are met, the modified resistance to the incipient spread of fire (MRISF) criteria may be applied, which require the temperature at the interface of the protection system and the timber to be not greater than 300°C during a fire resistance test performed in accordance with AS 1530.4 for the periods listed in Table A1.

Table A1 also includes Deemed-to-Satisfy minimum thickness of fire-protective-grade plasterboard .

Table A1: Massive timber panel – modified resistance to the incipient spread of fire (MRISF) requirements.

Requirements	Application	MRISF -min	Minimum Deemed-to-Satisfy fire-protective-grade plasterboard
Relaxed requirements for timber elements not less than 75 mm x 75 mm without cavities/voids or cavities/voids filled with non-combustible material	Inside a fire-isolated stairway or lift shaft	20	1 layer x 13 mm thick
	External walls within 1 m of an allotment boundary or 2 m of a building on the same allotment	45	2 layers x 13 mm thick
	All other applications	30	1 layer x 16 mm thick

Refer to Appendix E3 of this Guide for a more detailed description of how the RISF and MRISF criteria should be applied to elements such as walls, floors and service penetrations.

A.4 Enclosure Fires with Fire-protected Timber Building Elements

The objective of the fire-protective coverings is to prevent or delay ignition of the timber structural member, so that the response to an enclosure fire will be similar to non-combustible elements and masonry or concrete and so that the enclosure fire severity will not be increased due to the additional fire load presented by timber construction:

- during the growth period and
- prior to fire brigade intervention or burn-out of the contents, in the event of failure of the prescribed automatic fire sprinkler system and progression of the fire to the post-flashover phases.

The application of fire-protective coverings to timber is also known as encapsulation.

The performance of fire-protected timber was demonstrated to fulfill these objectives in comparative full scale fire tests undertaken with room enclosures lined with fire-protective-grade plasterboard[5,31].

The test configuration is shown schematically in Figures A3 and A4. It comprised an enclosure with internal dimensions 4 m x 4 m x 2.4 m high, with an opening of 2 m wide x 1.2 m high located in the centre of the front wall with the sill at a height of 0.5 m above the floor. The façade and corridor related to other research studies and are not discussed further here.

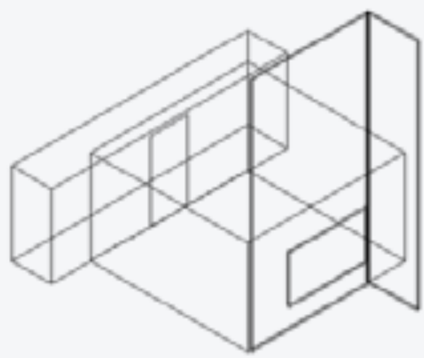


Figure A3: Schematic of test configuration used for comparative testing of fire-protected timber construction and non-combustible construction.

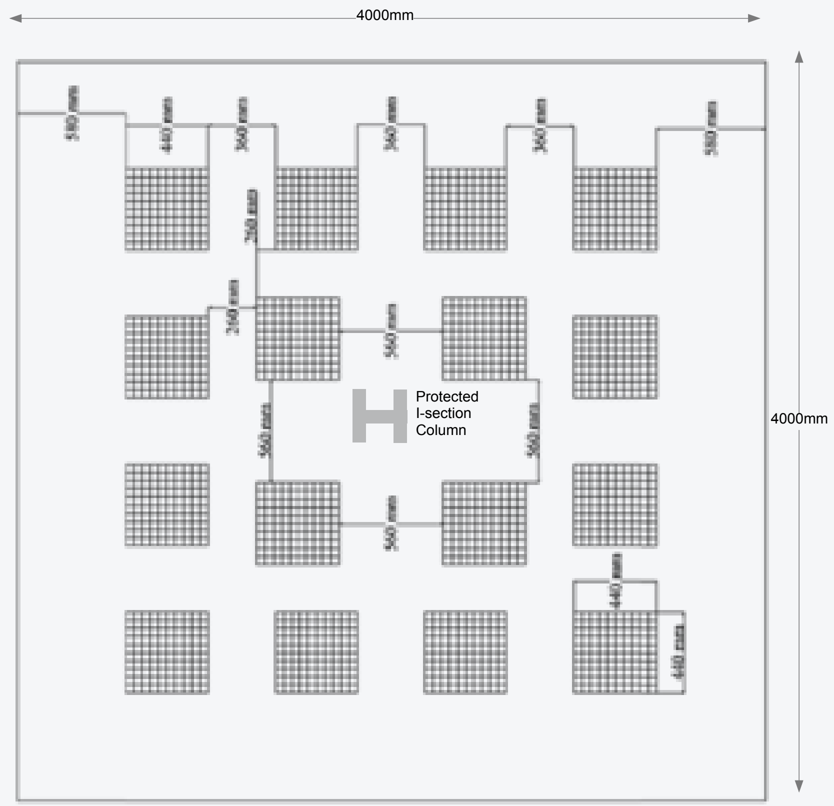


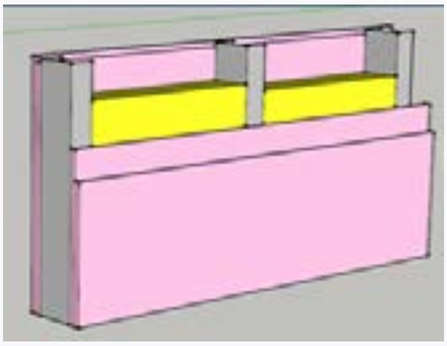
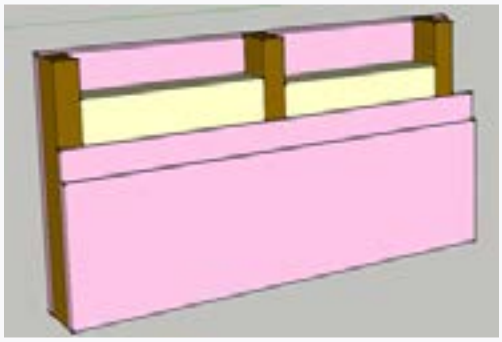
Figure A4: Plan of test enclosure showing crib layout and target fire-protected column.

A steel column protected by ceramic fibre was provided within the enclosure, as shown in Figure A5, to provide an indication of the comparative fire severity of the enclosure fires in addition to thermocouple trees measuring the enclosure temperature.

Figure A5: Test enclosure configuration showing protected steel column, timber cribs and thermocouple trees.

Both enclosures were lined with the same thicknesses of fire-protective-grade plasterboard to achieve the same nominal FRL of 90/90/90. Further details are provided in Table A2.

Table A2: Comparative test configurations.

Steel-framed non-combustible control	Fire-protected timber-framed construction
	
Wall Construction	
Steel studs Fire-protective covering – two layers of 13 mm fire-protective-grade plasterboard Non-combustible insulation	Softwood timber studs Fire-protective covering – two layers of 13 mm fire-protective-grade plasterboard Combustible insulation
Ceiling Construction	
Steel I-Joists Fire-protective covering – two layers of 16 mm fire-protective-grade plasterboard fitted to furring channels Non-combustible insulation Particleboard flooring	Timber I-Joists Fire-protective covering – two layers of 16 mm fire-protective-grade plasterboard fitted to furring channels Combustible insulation Particleboard flooring
Imposed Fire Load 740 MJ/m^2	**Imposed Fire Load 740 MJ/m^2**

The results summarised in Figure A6 show that there was no increase in the severity of the fire based on the following parameters measured during the test:

- enclosure temperature
- temperature of a protected column within the enclosure
- temperature on the non-fire side of the walls
- temperatures within the wall cavities
- temperatures on the unexposed side of the ceiling.

The comparative test fires incorporated initiation and development, and transition to fully developed and subsequent decay stages of a fire. The fully developed stage included periods of strong ventilation-controlled burning just after flashover with transition to a fuel-controlled regime.

The control test had to be terminated after 66 minutes due to failure of the ceiling system, whereas the timber-framed test was terminated after 114 minutes due to ignition of the ceiling insulation and observed burning droplets. It should be noted that the NCC requirements prohibit the use of combustible insulation in fire-protected timber construction, removing the risk of ignition of combustible ceiling insulation.

Temperatures measured within the wall cavities and on the upper surface of the ceiling confirm the earlier degradation of the steel-framed construction compared to timber-framed construction (refer Figure A6), which indicate that the steel-framed wall systems are more susceptible to degradation in performance due to rapid heating rates than timber-framed studs.

The greater susceptibility of steel-framed construction compared to timber-framed construction, when exposed to heating rates greater than the standard fire resistance test heating regime, has been observed in other studies (e.g. Li et al.[35]) and the earlier degradation can be explained to some extent by the higher thermal expansion of steel tending to open up joints and weaken fixings.

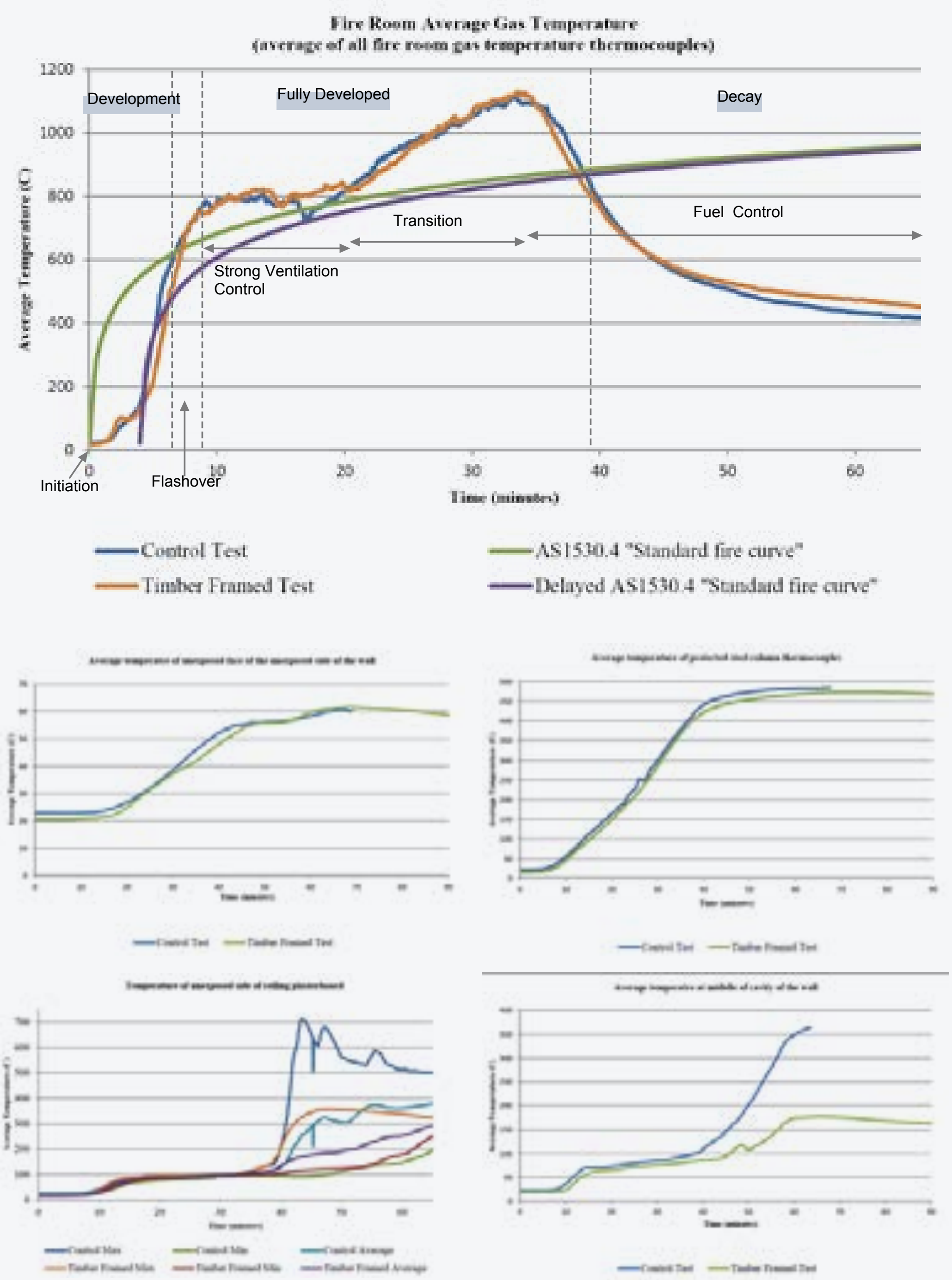


Figure A6: Results of comparative testing of non-combustible and fire-protected timber-framed construction.

The timber frame temperatures within the wall measured during the test peaked just below 300°C (see Figure A7) and the maximum temperature measured on the unexposed face of the ceiling reached a maximum of just above 350°C during the first 66 minutes, for which comparative data is available.

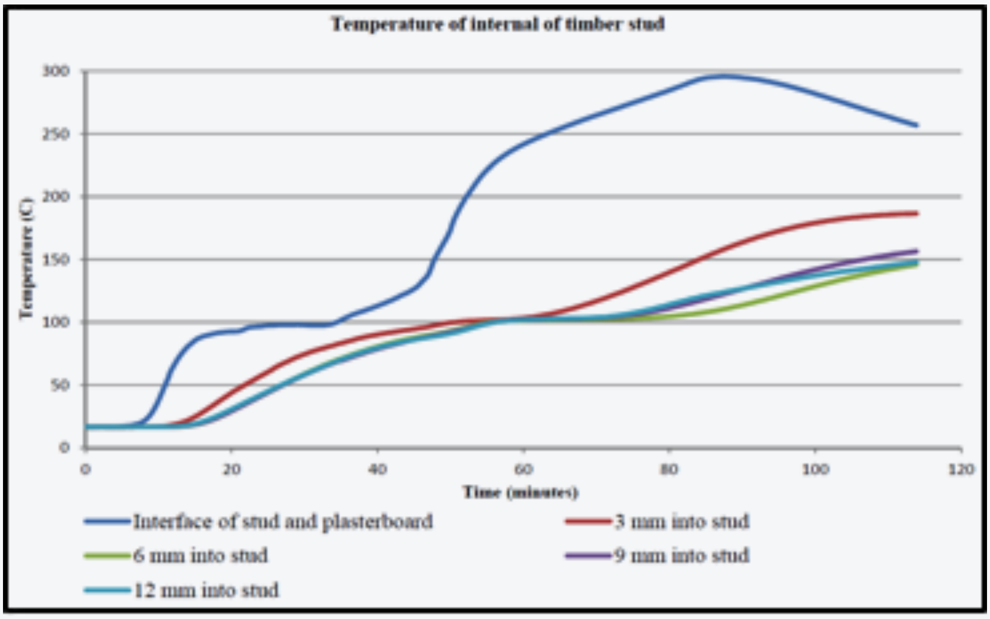


Figure A7: Timber frame wall temperatures.

The above comparative test demonstrated that the behaviour of the enclosure fire was not changed as a consequence of the use of timber construction with fire-protective linings that maintain timber temperatures below 300–350˚C. Therefore the objectives for fire-protected timber construction without fire brigade intervention or the impact of automatic fire sprinklers were satisfied.

Fire severity is a function of the ventilation conditions, fire load and lining properties. As the reliability of all fire protection systems is not 100%, the fire-protective coverings may fail in extreme cases; however, in most scenarios the fire will be suppressed or controlled as a result of automatic suppression by the sprinklers or by fire brigade intervention. This is likely to occur substantially before burnout of the contents for buildings designed in accordance with the Deemed-to-Satisfy requirements for mid-rise buildings. The multi-scenario analysis described in this Guide considered the probability and consequences of all the above scenarios.

A.5 Enclosure Fires with Exposed Timber Elements

Timber elements of construction may be exposed in buildings as part of the architectural design or may become exposed during a fully developed fire as fire-protective coverings degrade and fall away.

The impact of the additional exposed timber on enclosure fires is discussed in the following sub-sections.

A.5.1 Fire Initiation and Development

If timber elements are exposed in normal service, they will need to satisfy the relevant NCC requirements for wall and ceiling linings and floor coverings that seek to reduce the risk of lining materials and floor coverings unduly accelerating the rate of fire growth during the fire initiation and development phase (refer NCC Specification C1.10).

Since the primary focus of this Guide is mid-rise fire-protected timber buildings, which require non-combustible fire-protective coverings to be applied, the impact of combustible linings on the rate of fire growth during the fire initiation and development phase of an enclosure fire will not be considered in detail. Information on the fire performance of exposed timber linings, floor coverings and attachments during the fire initiation and development phase reference can be found through the following link, which provides test results for timber species relevant to the NCC Deemed-to-Satisfy pathway:

http://www.woodsolutions.com.au/Articles/Resources/Fire-Hazard-Properties-Floor-Coverings.

WoodSolutions Technical Design Guide #19: *Alternative Solution Fire Compliance Internal Linings* provides guidance in relation to the NCC performance pathway.

A.5.2 Fully Developed Fires

If additional timber elements are exposed to a fully developed fire, the effective enclosure fire load will be increased. The impact of this increase will primarily depend upon the burning regime at the time of exposure, the surface area of timber and mass of timber exposed, and the fire resistance of the element. The types of adhesive used in the manufacture of engineered timber products can also be significant under some circumstances.

The following cases are used to explain the potential impacts of exposed timber elements:

Case 1: Fully developed ventilation controlled fire prior to exposure of the timber.

If the fully developed fire is close to stoichiometric conditions or ventilation controlled prior to exposure of the additional timber elements, temperatures within the enclosure are unlikely to increase and may decrease – in some instances – if large areas of timber are exposed, because additional energy is consumed, degrading the wood to produce and heat volatiles that are then lost from the enclosure without undergoing combustion. Under these circumstances, flame extension from openings is likely to extend as the unburnt volatiles may undergo combustion as they mix with air outside the enclosure.

This was demonstrated in a test series reported by Hakkarainen[36]. A series of comparative natural fire enclosure tests were undertaken, which included exposed CLT panels, protected CLT panels and protected lightweight timber-frame construction. The same imposed fire load of approximately 720 MJ/m^2 of floor area and ventilation conditions were employed in all tests. The enclosure was 4.5 m x 3.5 m x 2.5 m high, with a 2.3 m wide x 1.2 m high window and also included a simulated façade above the opening.

The specimen configurations are summarised in Table A3 together with the observed performance of the plasterboard linings, test duration and reason for termination.

Table A3: Hakkarainen et al. tested constructions.

Test	Structural Elements	Fire Protection	Retention of Protection	Test Duration – mins (termination reason)
Test 1	CLT walls and floor/ceiling	None – exposed	Not applicable	50 (excessive flaming*)
Test 2	CLT walls and floor/ceiling	12.5 mm standard plasterboard	Fell away from ceiling at tops of walls approx. 18 minutes	46 (malfunction of smoke venting system)
Test 3	CLT walls and floor/ceiling	15.4 mm fire-grade plasterboard over 12.5 mm standard-grade plasterboard	First layer of boards fell away from ceiling after 27 minutes,	46 (malfunction of smoke venting system)
Test 4	Timber frame with mineral fibre insulation	15.4 mm fire-grade plasterboard over 12.5 mm standard-grade plasterboard	First layer of boards fell away from ceiling after 32 minutes	48 (burn through of ceiling)

* It is not clear whether Test 1 was terminated due to limitations of the test facility or failure of the elements of construction.

Figure A8 shows the mean enclosure temperatures as measured by the central thermocouple tree extracted from Hakkarainen[36] for each of the configurations summarised in Table A3. The time/temperature plot for the first six minutes (pre-flashover) was similar for all cases.

The mean temperature of the enclosure with unprotected CLT was similar to the CLT enclosure protected by standard plasterboard. This was probably due to the standard plasterboard degrading and falling away.

The mean temperatures of the CLT and lightweight timber-framed enclosures protected with fire-grade plasterboard were similar to each other.

It is noteworthy that the mean enclosure temperatures for the unprotected or partially protected CLT were substantially below the fully protected CLT and lightweight timber frames for the first 30 minutes after flashover.

Beyond the first 30 minutes after flashover, as the rate of burning of the fire load simulating the contents reduced, the temperatures of the fully protected timber enclosures started to reduce as the fire approached the decay phase but the temperatures of the enclosures with exposed CLT started to increase. The differing behaviours can be explained by considering changes in the burning regime within the enclosure. The combination of the contents and exposed CLT produced a strongly ventilation controlled fire after flashover, reducing the combustion efficiency. After about 30 minutes, the temperatures started to increase as the fire approached stoichiometric conditions because the fire load simulating the contents had been consumed.

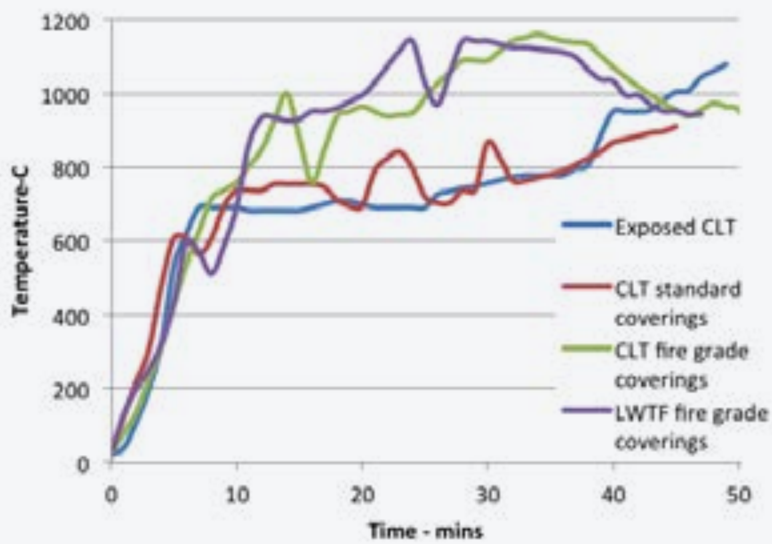


Figure A8: Average enclosure temperatures with and without plasterboard coverings extracted from Hakkarainen[36].

Unfortunately, three of the tests were terminated between 46 and 50 minutes and therefore comparisons of the potential fire duration, flame extension from enclosures and subsequent behaviour of the fire cannot be made. Similar observations were also made in a more recent study by Li, X et al.[35].

Case 2: Fully developed fuel controlled fire prior to exposure of the timber.

If the fully developed fire is fuel controlled prior to exposure of the additional timber elements, temperatures within the enclosure may increase since there may be sufficient excess air available within the enclosure for combustion of the additional volatiles produced by the timber. However, if there are large timber surfaces exposed, the increased rate of production of volatiles may change the burning regime to ventilation control and – depending upon the excess fuel factor – enclosure temperatures may decrease but as noted for Case 1 flame extension from the enclosure may increase.

Case 3: Fully developed fire transition to the decay phase

As fuel is consumed, the fire will decay and will generally be fuel controlled. The presence of additional exposed timber elements will generate additional volatiles that will tend to extend the fully developed fire phase. The magnitude of the extension of the fully developed phase will depend upon the rate of production of volatiles from the remaining contents and exposed timber element surfaces, among other things. If the contents are fully or substantially consumed before the timber elements, it is possible for the fully developed fire to continue – depending upon the enclosure configuration, the area of exposed timber surfaces, etc.

This was demonstrated in a series of tests performed by Carleton University and reported by McGregor[37] to investigate the contribution of CLT panels to room fires. The clearest comparison can be obtained from Tests 4 and 5. These tests were performed in an enclosure constructed of CLT panels with internal dimensions 3.5 m x 4.5 m x 2.5 m high with an opening 2 m high x 1.07 m wide. Furnishings/contents representing bedroom fire loads of 553MJ/m^2 and 529MJ/m^2 for Tests 4 and 5, respectively, were provided.

The CLT panels were exposed in Test 5 and protected with two layers of 13 mm fire-grade plasterboard in Test 4. In Test 4, there was no contribution from the CLT, with the plasterboard providing full protection.

From examination of the average enclosure temperatures, it can be observed that until the fire load (excluding the CLT) had been substantially consumed, the enclosure temperatures were similar – the time lines are offset to exclude the pre-flashover phase as shown in Figure A9.

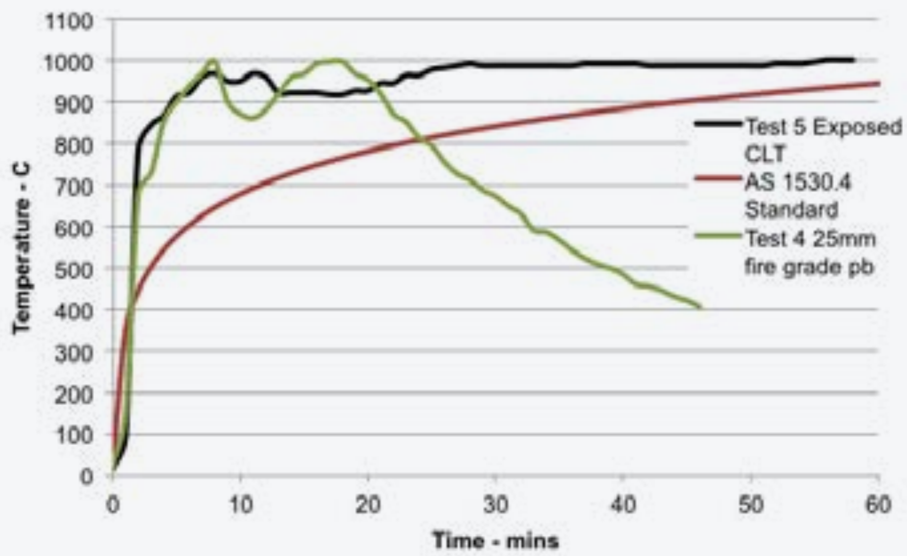


Figure A9: Average enclosure temperatures with and without plasterboard coverings extracted from McGregor[37].

For the protected enclosure, the fire burnt out and decayed; whereas, in Test 5 the CLT continued to burn, extending the duration of the fully developed fire beyond 62 minutes, at which stage the test was terminated.

A.6 External Fire Spread

A.6.1 External Fire Spread Scenarios

There are four common exposures that may initiate external fire spread, which are summarised in Figure A10.

Scenario 1: Fire spread from adjacent buildings to the subject building

Scenario 1 relates to the risk of fire spread from adjacent properties to the subject building and it is addressed under the NCC Deemed-to-Satisfy Provisions by the specification of:

- minimum separation distances for openings in walls
- non-combustible construction for mid-rise construction (Type A or B construction)
- fire-resisting construction – depending on the distance from the potential fire source.

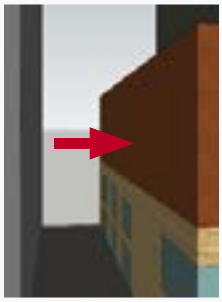
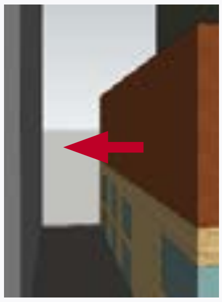
Scenario 1	Fire spread from adjacent buildings to the subject building	
Scenario 2	Fire spread from the subject building to adjacent buildings	
Scenario 3	Fire spread from an external fire source adjacent to the facade other than adjacent buildings, e.g. car fire, waste bin fire, furnishings on balconies etc.	
Scenario 4	Vertical fire spread originating from an internal fire typically from a fully developed fire within the building spreading to the façade / external walls	

Figure A10: External fire spread scenarios.

Scenario 2: Fire spread from the subject building to adjacent buildings

Scenario 2 relates to the risk of fire spread from the subject building and it is addressed under the NCC Deemed-to-Satisfy Provisions by the specification of:

- minimum separation distances for openings in walls
- non-combustible construction for external walls for mid-rise construction (Type A or B construction) to avoid combustion of the façade increasing the risk of fire spread to adjacent structures
- fire-resisting construction to avoid the building collapsing onto adjacent properties, limiting the maximum fire compartment size and preventing the opening up of additional openings
- automatic fire sprinklers in buildings above 25m high reducing the probability of a fully developed fire occurring that may threaten adjacent properties.

A verification method is also provided in the NCC to address fire spread between adjacent properties (Scenarios 1 and 2). The requirements are quantifiable, such that the building itself is required not to impose a heat flux greater than limits specified as shown in Table A4, for various distances from the boundary or an adjoining property or road. The subject building is also required to resist ignition when exposed to the heat flux stated in Table A4, if it is constructed within the nominated distances of another building or boundary.

Table A4: Maximum heat flux for various distances from the boundary and adjacent buildings.

Distance from Boundary	Distance between Buildings (m)	Maximum heat Flux kW/m^2
On the boundary	0	80
1 m from the boundary	2	40
3 m from the boundary	6	20
6 m from the boundary	12	10

Scenario 3: Fire spread from an external fire source adjacent to the façade

The risks associated with Scenario 3 are predominately addressed by the Deemed-to-Satisfy requirement in the NCC for non-combustible construction of external walls.

Scenario 4: Vertical fire spread originating from an internal fire

The risks associated with Scenario 4 are predominately addressed by the Deemed-to-Satisfy requirement in the NCC for non-combustible construction of external walls and the following three options for vertical separation of openings:

Spandrel panels: A section of external wall, curtain wall, or panel above an opening that is 900 mm or higher and extends at least 600 mm above the upper floor surface and is made from non-combustible material with a minimum FRL of 60/60/60, as shown in Figure A11.

Where curtain or panel walls are used, any gaps between the surface and the building's structure must be packed with a non-combustible material that will withstand thermal expansion and structural movement of the walling without the loss of seal against fire and smoke.

Horizontal Projection: Projects outwards from the external face of the wall not less than 1,100 mm; and extends 450 mm beyond the openings and is made from non-combustible material with a minimum FRL of 60/60/60, as shown in Figure A11.

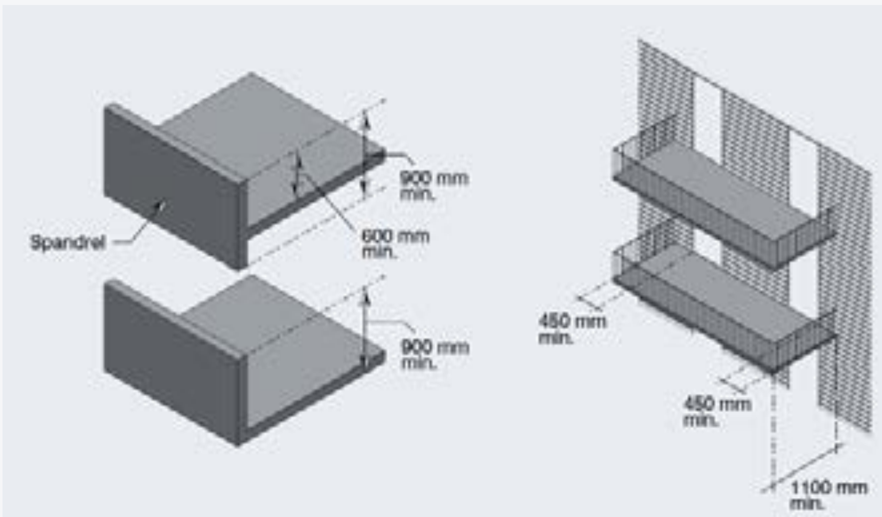


Figure A11: Vertical separation of openings.

Source: WoodSolutions Technical Design Guide #18: Alternative Solution Fire Compliance, Façades

Automatic Sprinkler Fire Protection: The requirements for fire separation are waived if an automatic fire sprinkler system is provided throughout the building.

The efficacy of spandrel panels and horizontal projections is very sensitive to the ventilation conditions of the fire venting from the opening below. This has been demonstrated in numerous studies.

The results summarised below were obtained from the compartment fire tests described in Section A.4: Enclosure Fires with Fire-protected Timber Building Elements. A cement sheet faced façade was constructed above the opening to a height of approximately 6m above ground level and included a wing wall (re-entrant detail). One test included a 600 mm horizontal projection above the opening and the other test had a vertical façade. Within the enclosures, the burning regimes were similar, and varied during the fire from strongly ventilation controlled to fuel controlled, providing a useful comparison between façades with and without horizontal projections over a range of conditions. The opening was 2 m wide x 1.2 m high located in the centre of the front wall with the sill at a height of 0.5 m above floor level.

The images in Figure A12 showing the different burning regimes at various times and the results presented in Table A5 have been extracted from Technical Design Guide #18. Further details can be obtained from England and Eyre[5,31].

2 mins Growth Phase

15 mins Fully developed ventilation controlled phase

35 mins Transition to fuel controlled phase

50 mins Decay

Figure A12: Burning regimes of enclosure tests.

Table A5: Incident heat flux and gas temperatures over façades with different burning regimes.

	Test Time (mins)	Burning Regime	Enclosure Temperature (Co)	Heat flux 1.5 m above opening (kW/m²)	Heat flux 3 m above opening (kW/m²)	Temperature 1.5 m above opening (°C)	Temperature 1.5 m above opening (°C)
Flat Facade	2	Growth (fuel controlled)	50	2	1	46	39
Horizontal Projection			67	1	1	53	24
Flat Facade	20	Strong vent controlled	813	104	43	1000	741
Horizontal Projection			831	67	15	639	461
Flat Facade	28	Vent controlled	1018	65	29	777	433
Horizontal Projection			1029	41	11	467	386
Flat Facade	35	Stoichiometris (approximately)	1090	30	18	636	417
Horizontal Projection			1088	13	5	312	313
Flat Facade	40	Decay phase (fuel controlled)	785	20	12	467	303
Horizontal Projection			763	17	5	420	262

The results show that even modest horizontal projections can significantly reduce the incident heat flux on the façade, but with ventilation-controlled fires the 900 mm vertical separation between openings would be unlikely to prevent fire spread with the ventilation conditions in this test, since incident heat fluxes over 100kW/m^2 were measured 1.5 m above the opening.

Figure A13 also demonstrates the potential impact of re-entrant details increasing flame adhesion and extending the flames further (estimated to peak at about 7 m above the opening).

Figure A13: Maximum flame extension estimated to be more than 7 m above opening.

The fire load of the test compartment was 41 kg/m^2 (kg wood per m^2 floor area), which equates to about 740 MJ/m^2 based on a heat of combustion of 18 MJ/kg compared to the 25 kg/m^2 suggested in ISO 13785-2:2002[38] for evaluation of façades. The selected fire load was intended to be representative of a relatively high fire load for residential occupancies, and therefore produced a strongly ventilation-controlled fire until some of the fuel load and fuel surface area had reduced.

Of the three Deemed-to-Satisfy options, the most effective is therefore to minimise the risk of a fully developed fire occurring in the first place through the provision of automatic fire sprinkler systems.

The additional requirement for non-combustible construction of external walls may limit or retard the spread of fire in some instances if the automatic fire sprinkler system were to fail or in the event of an external fire, but there would be a residual risk of fire spread between floors.

A.6.2 Fire-protected Timber Performance

Scenario 1: Fire spread from adjacent buildings to the subject building

Since the fire-protective coverings applied to fire-protected timber are required to be non-combustible, ignition due to the imposition of heat from an adjacent building will not occur if the fire-protective coverings provide sufficient insulation to prevent the temperature of the underlying timber reaching ignition temperatures (typically in excess of 300°C for common configurations). Under these conditions, the behaviour will be similar to a non-combustible external wall subject to any additional screening provided to protect the fire-protective coverings from weather being non-combustible.

Scenario 2: Fire spread from the subject building to adjacent buildings

If the fire-protective coverings prevent the timber elements being involved in the fire, the severity of a fully developed fire would be similar to that of an equivalent enclosure of non-combustible construction (see Appendix A.4: Enclosure Fires with Fire-protected Timber Building Elements). Therefore, the heat flux imposed on adjacent structures would also be similar.

A series of four large scale apartment encapsulation tests were undertaken by NRC as part of a recent investigation into mid-rise wood construction which has been summarised by Su and Lougheed[39].

Four tests were conducted using a three-storey simulated building with the fire ignited on the mid-level. A brief description of each form of construction tested; peak heat fluxes measured in front of the window openings; and total heat release rate from the fires are summarised in Table A6.

Table A6:Summary of peak heat flux measurements in front of window openings and peak heat release rates from Canadian encapsulation tests.

Test Ref	Description and Details of Internal Linings	Heat Flux kW/m² from openings				Max HRR – MW*
		Bedroom		Living Room		
		2.4m	4.8m	2.4m	4.8m	
LWF1	Timber-framed, protected with 2 layers of type X pb 12.7 mm thick. Ceiling fixed via steel furring channels at 405 mm centres	23	7	21	7	8**
CLT	Walls 105 mm CLT, Floor 175 mm, CLT all protected by 2 layers of type X pb 12.7 mm thick direct fixed	25	9	23	7	8.4
LSF	Walls – Steel studs protected with one layer type X pb 15.9 mm thick. Ceiling – Steel joists protected by 1 layer type X pb 12.7 mm thick fixed via steel furring channels at 610 mm	25	9	33	10	10.5
LWF2	As LWF1 but with only 1 layer of standard pb 12.7 mm thick applied to external wall	28	10	25	10	10.6

** HRR includes both combustion within the structure and in the plumes outside the test building.*
*** This was reported as an estimate.*

Unfortunately, direct comparisons between the test results are difficult because of the differing methods of application of the fire-protective coverings; different encapsulation levels; and inclusion of non-loadbearing internal timber walls with minimal encapsulation (12.7 mm standard plasterboard) for the experiments with timber frames and CLT.

However the following observations are relevant:

- The results from test LWF1 and CLT generally yielded similar results with respect to HRR and radiant heat from openings and the levels of encapsulation were similar.
- The non-combustible steel-framed test LSF yielded higher peak radiation levels and HRR. This was due to the failure of the non-loadbearing external wall which increased the opening size in the living room. This had the effect of increasing the rate of burning within the living room enclosure but also increasing the rate of release of volatiles from the enclosure. The larger opening also increased the size of the radiant heat source increasing radiation levels in front of the opening and reducing the duration of the fire. As a result, a direct comparison of the results from tests LWF1 and CLT cannot be made.
- The external openings in test LWF2 did not appreciably increase due to the early degradation of the standard plasterboard but the internal timber framework was exposed, effectively simulating a gross defect with an encapsulation system (i.e. substitution of Type X board with standard board). This increased the maximum HRR and radiant heat released from the living room and bedroom openings compared to tests LWF1 and CLT.

In summary, the results showed that encapsulation can appreciably reduce fire severity in timber buildings, and hence radiation levels in front of openings, but other factors such as the size of ventilation openings are also important.

Scenario 3: Fire spread from an external fire source adjacent to the façade

The NCC requirements for fire-protected timber in mid-rise buildings for external walls require as a minimum the same level of protection against ignition/incipient spread of fire as the inner face. For buildings within 1 m of a fire source feature (e.g. allotment boundary), or 2 m of an adjacent building, the massive timber provision for fire-protective coverings is not applied and the higher levels of protection required for general timber structures are adopted. The severity and duration of an external fire source is unlikely to exceed that of a fully developed fire and therefore the performance of fire-protected timber would be expected to be similar to that of non-combustible construction. (Note: any additional façade materials such as weather barriers must also be non-combustible).

Scenario 4: Vertical fire spread originating from an internal fire

The test results and discussion in Appendix A.6.1: External Fire Spread Scenarios/Scenario 4 are directly applicable to fire-protected timber, since the peak exposure of the external wall is likely to be the result of combustion of the contents only and the external levels of fire protection are as a minimum similar to the internal protection levels. In addition, mid-rise fire-protected timber buildings are required to have automatic fire sprinkler protection, greatly reducing the probability of a fully developed fire occurring.

A.6.3 Exposed Timber Performance

Scenario 1: Fire spread from adjacent buildings to the subject building.

If the external wall includes unprotected timber elements, ignition and fire spread may potentially occur if the incident radiant heat significantly exceeds the critical heat flux for ignition (typically assumed to be approximately 12kW/m^2). A separation distance between buildings of 12 m (6 m from the boundary) is required from Table A4 to maintain radiation levels below 10kW/m^2.

The selection of timbers with relatively high resistance to ignition may enable modest increases in the radiant heat that can be resisted by exposed timber façades.

For example, Figure A14 shows the time to ignition calculated using the Janssens' Procedure[40,41] applied to cone calorimeter data for Grey Ironbark[42]. The data points used to derive the constants were between radiant heat fluxes of 25 and 60 kW/m^2, but the critical heat flux derived of approximately 12.3 kW/m^2 gives some confidence in the predicted times to ignition below 25kW/m^2.

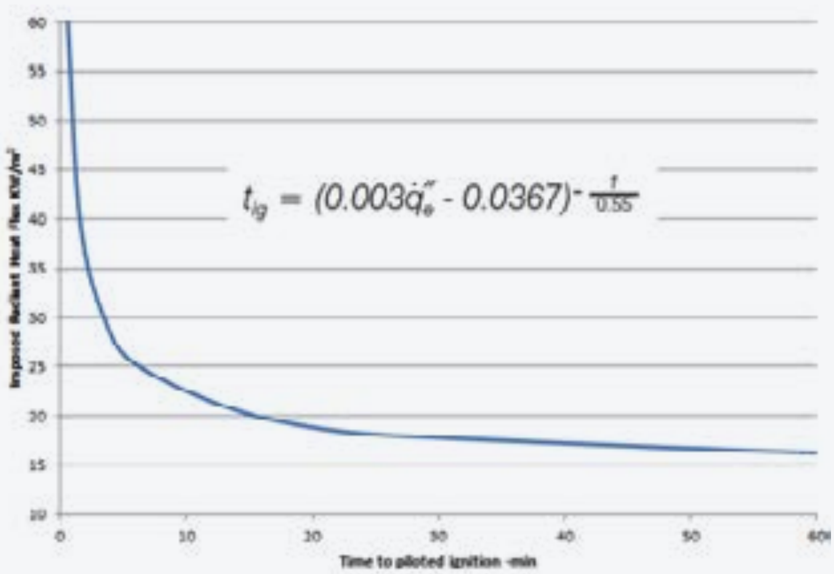


Figure A14: Time to piloted ignition of Grey Ironbark exposed to radiant heat from Richardson and England[42].

For an incident radiant heat flux of 17.5 kW/m^2, the time to piloted ignition can be calculated to be greater than 30 minutes, but this reduces to about 15 minutes for an incident radiant heat of 20kW/m^2, illustrating that the results are very sensitive as heat fluxes approach 20kW/m^2.

In some instances it may therefore be useful to interpolate the limiting heat fluxes for distances between 3 m and 6 m from the boundary. For example, subject to agreement with the authority having jurisdiction, the following equation could be used to interpolate between the specified boundary distances in Table A6 above:

$Q = 39.6 - 16.88 \log_e(d)$

Where Q is the heat flux (kW/m^2) and d is the distance from the boundary (m). The correlation is shown in Figure A15.

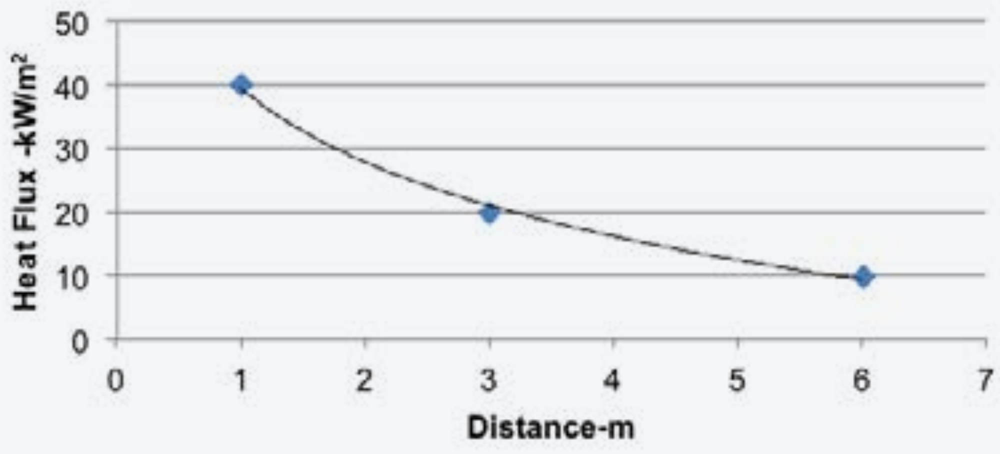


Figure A15: Interpolation of separation distances prescribed in CV1.

For example, an incident radiant heat flux of 17.5 kW/m2 corresponds to a separation distance of 3.7 m. Without interpolation, a separation distance of 6 m would be required.

The performance of timbers can be improved by the use of fire retardants. To be effective, the fire retardants would need to have sufficient durability for external use and be able to retard ignition over lengthy exposure periods to high radiant heat fluxes.

Scenario 2: Fire spread from the subject building to adjacent buildings

This scenario is closely aligned to Scenarios 3 and 4, in that, if a fire ignites the building façade and propagates across the external surfaces of the building, a potential consequence is an increased risk of fire spread to adjacent structures, compared to non-combustible construction and fire-protected timber construction. The probability of fire spread can be reduced by:

- preventing ignition
- limiting fire spread or the consequences if ignition occurs – typical options include one or more of the following measures:
  - controlling material properties (e.g. timber selection or use of fire retardants)
  - controlling timber element configurations
  - limiting the size of 'packages' of exposed timber and separating packages such that fire spread is limited to a single package (e.g. use exposed timber for features on the façade and/or break up the façade with horizontal projections)
  - increased separation distances for combustible areas from adjacent buildings.

Scenario 3: Fire spread from an external fire source adjacent to the façade

This scenario includes fire starts on balconies, and there have been a number of significant fires involving composite panels resulting in rapid fire spread (e.g. the Lacrosse Docklands[43]). Timber does not exhibit some of the burning characteristics that contributed to the severity of these incidents but, if combustible materials are used on the façades of mid-rise buildings, the response to external fire scenarios need to be considered when developing a performance solution. (NCC Deemed-to-Satisfy Provisions generally require non-combustible construction or fire-protected timber construction for external walls.) In some instances, Scenario 3 may be considered less severe than Scenario 4 and therefore Scenario 4 is commonly used for design purposes, but each case should be considered on its merits.

Scenario 4: Vertical fire spread originating from internal fires

As discussed above, the size of plumes projecting from openings during a fully developed fire and associated flame extension is dependent on the ventilation conditions, the opening configurations and façade configurations. For fuel controlled fires, there may be minimal flame extension but for strongly ventilation-controlled fires flame extensions can be substantial, as demonstrated in Figure A13.

If the façade of the building includes exposed combustible components, flame extensions can be further increased as volatiles are released and the risk of other modes of fire spread such as cavity fires may be increased.

The primary method to address this mode of spread is the use of automatic fire sprinklers to minimise the risk of a fully developed fire occurring but, if combustible façade systems are intended to be used, their performance should also be evaluated (ignoring the impact of sprinklers) to ensure a robust building solution is provided.

AS 5113:2016 Fire propagation testing and classification of external walls of buildings identifies appropriate test methods and performance criteria.

Sources of additional information are:

- Fire Hazards of Exterior Wall Assemblies Containing Combustible Components[64]
- Fire Safety Engineering Design of Combustible Façades[51]
- WoodSolutions Technical Design Guide #18: *Alternative Solution Fire Compliance, Façades*.

A.7 Cavity Fires

Cavities within fire-resisting construction can provide paths for the spread of fire that can bypass the boundaries of a fire-resisting compartment, potentially compromising a fire safety strategy. Spread through cavities can be accelerated by the presence of combustible materials and linings within the cavities.

Fire spread through cavities/concealed spaces is relatively infrequent but, when it does occur, fire can spread rapidly and the seat of the fire may be difficult to locate, presenting challenges to fire fighters. While not unique to timber buildings, there have been major incidents involving fire spread through cavities in timber buildings.

Common causes of fire starts within cavities are electrical faults or hot works during maintenance activities but enclosure fires can also spread to cavities and via cavities to other enclosures.

For mid-rise timber buildings designed to the NCC 2016 Deemed-to-Satisfy solutions, a multi-tiered approach has been adopted to provide a robust fire safety strategy that is not solely reliant on any one element, incorporating the following measures to prevent the fire spreading to the cavity in the first place:

- Fire sprinkler system installed in accordance with Specification E1.5 of the NCC reducing the number of severe fires
- Specification of fire-protected timber, which requires fire-protective linings to provide resistance to the incipient spread of fire, in addition to contributing to the fire resistance of the element
- Application of the resistance to the incipient spread of fire criteria to service penetrations.
- Specification of cavity barriers to be fitted around windows and doors to maintain the integrity of the fire-protective linings.

If a fire does spread to a cavity or ignition occurs within the cavity the following measures have been specified in the NCC 2016 to minimise the consequences:

- Any insulation in wall and floor/ceiling cavities must be non-combustible to ensure that if insulation is provided within the cavities, it will tend to limit growth and fire spread and not accelerate it
- Cavity barriers at junctions with other fire-resisting elements of construction and at prescribed maximum centres are specified to restrict spread
- Larger floor cavities are required to have fire sprinklers fitted within the cavity in accordance with the requirements of NCC Specification E1.5, which will limit growth and fire spread within the protected areas
- The structural design should be robust such that progressive collapse is unlikely if a structural member fails to support the applied load.

The NCC Provisions recognise that massive timber panel construction is less susceptible to cavity fires, subject to appropriate detailing, and permits a modified resistance to the incipient spread of fire criteria to be adopted in some circumstances.

B Appendix B - Matters Raised by Stakeholders and Other Parties

Issue	Discussion	Outcome
1: Will the increased use of timber increase the fire growth rate?	The proposed variation relates predominately to walls/ shafts since the current Deemed-to-Satisfy (DTS) Provisions do not prevent the use of timber floors beams and columns for most applications. Where timber is to be used as part of an assembly required to be non–combustible or of concrete/masonry construction, it will be fire-protected. Therefore there will be no increase in the fire growth rate, which in most circumstances will be dominated by furnishings. The DTS lining controls also apply.	No increase in fire growth rate expected. The addition of automatic fire sprinklers will limit the size of larger fires in most scenarios for timber buildings, therefore the growth rate of larger fires will be reduced after activation of automatic fire sprinklers, providing a net reduction in effective growth rate.
2: Will the time to flashover be reduced by the use of timber?	The timber will not accelerate the time to flashover when used for an element required to be of non-combustible or masonry or concrete construction, because it will be protected with fire-protective coverings that are required to be non-combustible and protect the timber substrate during a flashover fire.	No reduction in the time to flashover and number of flashover fires will be reduced by more than 90%, because of the prescription of automatic fire sprinklers.
3: Will adhesives used in manufactured massive timber products reduce the time to untenable conditions?	General furnishings are expected to dominate the production of toxic gases during a fire because of the high volumes of synthetic upholstered materials, with contributions from the adhesives used in engineering products expected to be minimal. In addition, the proposed changes relate to the use of timber products protected by fire preventative coverings, which will be expected to prevent breakdown of the timber and adhesives until after untenable conditions have occurred in the enclosure, in the low probability event that the automatic fire sprinkler system fails.	The variations being considered in this study require protected timber, and automatic fire sprinklers are provided, which are expected to increase the time to untenable conditions providing a safer building. The Deemed-to-Satisfy smoke production limits in C1.10 of the NCC apply.
4: Are untenable conditions reached earlier or differently to normal residential fires?	Due to the use of preventative coverings, no change in the time to untenable conditions would be expected when compared to non-combustible elements or masonry or concrete construction. The introduction of automatic fire sprinklers will induce greater mixing/cooling of smoke after activation, but a significant net improvement in safety will be provided where automatic fire sprinklers are provided.	Untenable conditions more likely to be reached at a later stage in a fire, but sprinklers will modify how untenable conditions are reached close to the fire and a substantial net improvement in safety is expected.
5: Does plasterboard fall-off occur during a fire? If so, at what stage and what is the impact?	Whether plasterboard falls off and, if so, at what stage of a fire depends on many factors, including fire severity, type of plasterboard, thickness, fixing system, active fire protection measures, etc. For the elements of construction being considered in this study, a performance specification has been developed which requires a preventative covering that prevents the temperature of the interface with timber members exceeding either 250°C (timber-frame) or 300°C (massive timber) when exposed to the standard heating regime, to provide an opportunity for fire-fighting activities to begin – should the automatic fire sprinklers fail.	Plasterboard or other non-combustible fire-protective coverings would not be expected to fall off prior to sprinkler activation or when fire brigade intervention occurs within the most likely time frames. In the rare circumstances of sprinkler failure coincident with a slow fire brigade intervention time, the ability of the preventative coverings to remain in place will depend on a number of factors, including fire severity. The Monte Carlo analysis took all these factors into account and compared a building designed in accordance with the proposed changes with one that satisfies the 2015 NCC Deemed-to-Satisfy Provisions. If coverings fall off, the fire duration is increased in the modelling to evaluate the consequences.

Issue	Discussion	Outcome
6a: What is the impact when the facings fall away from timber-framed construction?	The impact will depend on what stage the fire has reached when the facings fall away. The Proposal-for-Change (PFC) to the NCC requires the facings to remain in place for a substantial period should a flashover fire occur to prevent ignition of the timber for sufficient time to facilitate fire-fighting activities. The boards are likely to remain in place for a substantial period after this stage and in many instances ar elikely to be in place after burnout of the contents. If the facings fall off, the timber frame will be exposed to the enclosure fire. This is most likely to occur while the fire is fully developed or in the decay stage. When the timber is exposed it will release volatiles and form a char layer reducing the rate of production of volatiles. If the timber is exposed whie the fire is ventilation controlled the enclosure temperatures are unlikely to increase due to a lack of oxygen. If the fire is fuel controlled, there may be an increase in enclosure temperature but the impact will be small because of the relatively small exposed surface area of timber.	The Proposal-for-Change (PFC) includes an automatic fire sprinkler system as the primary fire protection system minimising the risk of timber members being exposed in addition to the prescription of fire-protected timber. Notwithstanding this the analysis considered scenarios where the timber may be exposed and showed that the timber buildings provided a substantially greater level of safety than 2015 Deemed-to-Satisfy measures.
6b: What is the impact when the facings fall away from massive timber construction?	Refer to item 6a. Similar behaviour will be expected from massive timber except in some cases with laminated products a lamination may fall away, exposing fresh timber and possibly initiating short term growth, and the exposed timber surface area will be greater. As noted above, the inclusion of an automatic fire sprinkler system and use of fire-protected timber will offset any negative effects.	Refer to item 6a.
7: Could exposed timber systems increase fire severity, causing other fire-resistant elements to be over-run?	In theory, yes, but the likelihood of this happening with the specification of fire-protected timber and sprinklers is very low. The risk associated with these scenarios has, however, been evaluated in the analysis, with the fire duration/severity being increased to account for the contribution from the exposed timber for scenarios where coverings fail (exposing timber) and the impact on other fire-resistant elements has been modelled.	These scenarios were considered in the detailed analysis but, due to the range of mitigation measures including the provision of automatic fire sprinklers, a net improvement in fire safety was demonstrated.
8: Can timber reignite or ignited timber in cavities continue to burn and, if so, are special measures required?	Timber can reignite and continue to burn after the main fire is supressed in some instances and, although the probability is low, ignition of timber in cavities can also occur. Lightweight timber-framed construction is more susceptible because of the smaller cross section of timbers and potential for cavities behind coverings. The following special measures are provided to address this risk: • provision of fire sprinkler systems • specification of fire-protected timber to reduce the risk of ignition prior to fire brigade intervention (higher levels of protection are specified for timber-frame construction) • requirements for cavity barriers • any cavity insulation to be non-combustible. Notwithstanding the above precautions, as is the case with all fires, it will be necessary to monitor a fire to avoid re-ignition and incipient spread in the same way as any structural fire. Australian fire fighters are experienced in dealing with fires in timber-framed construction and may need to adapt some of these procedures for mid-rise timber buildings.	The PFC requires the following additional measures to mitigate the risk of re-ignition and fire spread through cavities: • provision of fire sprinkler systems • specification of fire-protected timber to reduce the risk of ignition prior to fire brigade intervention • requirements for cavity barriers • any cavity insulation to be non-combustible. The analysis showed an improvement in fire safety for a mid-rise timber buildings designed in accordance with the PFC compared to the control building complying with current NCC 2015 Provisions .

Issue	Discussion	Outcome
9: How is the strength and stability of the building addressed during and after a fire event?	This is a disproportionate collapse issue that should be addressed as part of the Structural Design for each building, as it should be for all other types of structures under NCC Provisions, e.g. BP1.1. A workshop was held with structural engineering experts to identify current approaches and determine if there was a need for specific advice relating to timber. The outcome of the meeting was that guidance was needed in relation to all forms of construction – not just timber. A Guide is being developed by WoodSolutions that, among other things, will require at least one level of redundancy to be provided to address the risk of disproportionate collapse and typical details for timber construction will be provided. The Monte Carlo analysis considered levels of redundancy and assumed major collapse if two or more groups of members fail. Fire spread through cavities in timber-framed construction has been identified as a special case and the Guide will require the structural design to additionally withstand the loss of two sections of walls directly above each other, providing increased redundancy to address reliability of cavity barriers.	This will be addressed through structural design process to avoid disproportionate collapse as required by current Provisions in the NCC for all buildings. To facilitate this, a Guide is being developed by WoodSolutions which will provide guidance to structural engineers. It will include specific advice for mid-rise timber buildings.
10: How will connections be protected under fire conditions?	Connections within engineered timber members, such as web connections, glued joints, etc, are required to be evaluated during the fire resistance test. Fire resistance of connections between elements will be maintained using well-established practices for timber elements of construction such as: • redundancy in connectors: example connections on both side of a fire-separating element • applying fire protection over the joint • use of sacrificial timber to protect metal connectors • fire-resisting plasterboard • concrete floor topping. To minimise the risk of poor design detailing, the existing range of WoodSolutions guides will be reviewed and expanded as necessary. The WoodSolutions guidance documents will also provide advice on suitable detailing to prevent disproportionate collapse.	Normal practices will be adopted based on standard details and/or results from fire resistance tests. Clear guidance will be provided in WoodSolutions Guidelines.
11: Is there a risk of outward collapse of massive timber external wall panels?	This question was asked at the structural engineers' workshop and there was a clear consensus that there is no increased risk of outward collapse. This is due to the low thermal expansion of timber, initial shrinkage as water is driven off and insulating properties minimising distortion, and thus induced eccentricity under fire conditions compared to other common building materials such as concrete and masonry. There is still a need for proper detailing of connections and, as noted in item 10, the existing range of WoodSolutions guides will be reviewed and expanded as necessary.	No increased risk of outward collapse. Normal practices for connections will be adopted based on standard details and/or results from fire resistance tests. Clear guidance will be provided in WoodSolutions Guidelines.

<table>
<tr><th>Issue</th><th>Discussion</th><th>Outcome</th></tr>
<tr><td>12: Is there a risk of Fires in Voids spreading rapidly?</td><td>Without appropriate mitigation measures, spread through cavities can occur, which in extreme circumstances could be rapid. This is most likely to occur with lightweight timber-framed construction, rather than massive timber construction where careful detailing can avoid cavities.
The PFC requires a broad range of measures to address this risk in a robust manner including:
• Automatic fire sprinklers to reduce the risk of severe fires spreading to cavities. They are also required to be fitted within larger cavities in accordance with AS 2118.1 providing additional protection.
• The specification of fire-protected timber to minimise the risk of ignition of protected timber members (higher levels of protection are specified for timber-framed construction).
• Insulation within cavities is to be non-combustible.
• Cavity barriers are specified to prevent or retard spread across compartment boundaries via cavities and spread to and from cavities around openings such as windows.
The detailed analysis took account of the results of studies into this form of spread and experimental data to assess the risks to compare the risk to occupants in the proposed timber building compared to the control building.</td><td>This risk will be managed through the specification of the following measures:
• Automatic fire sprinklers to reduce the risk of severe fires spreading to cavities. They are also required to be fitted within larger cavities in accordance with AS 2118.1 providing additional protection.
• The specification of fire-protected timber to minimise the risk of ignition of protected timber members (higher levels of protection are specified for timber-framed construction).
• Insulation within cavities is to be non-combustible.
• Cavity barriers are specified to prevent or retard spread across compartment boundaries via cavities and spread to and from cavities around openings such as windows.</td></tr>
<tr><td>13: Does timber construction expose fire fighters to increased risk?</td><td>A key outcome of the analysis is a significant reduction in the risk to fire fighters in medium rise timber buildings, largely resulting from the specification of automatic fire sprinklers and fire-protected timber. The fire sprinklers will reduce the number of high-risk fully developed fires that the fire brigade have to respond to by a factor of approximately 10, and the fire-protected timber in most instances will prevent ignition of the timber substrate before fire brigade intervention occurs, providing similar outcomes for scenarios where the sprinkler system fails to those of the control building.</td><td>A significant reduction is expected in the risk fire fighters are exposed to.</td></tr>
<tr><td>14: Is there a need to change fire-fighting procedures?</td><td>There is extensive experience fighting fires in low-rise timber-framed construction in Australia and the same general principles can be applied to mid-rise construction. During stakeholder engagement, extensive discussions have been undertaken with the fire authorities to brief them on the proposed forms of construction so that they can adapt fire-fighting procedures as appropriate.
Some suggestions have been identified include identifying and carrying appropriate tools to gain access to cavities and the use of thermal cameras to determine concealed hot spots.</td><td>Some minor adjustments to fire-fighting procedures may enhance the effectiveness of fire brigade intervention in mid-rise timber buildings and the fire authorities have been involved throughout the development of the PFC. The specification of Deemed-to-Satisfy solutions for mid-rise timber buildings will help standardise construction details and reduce the risk of fire fighters being exposed to ad hoc arrangements, improving safety and effectiveness of fire fighters.</td></tr>
<tr><td>15:What evidence of FRLs will be required?</td><td>Suppliers will need to provide evidence of FRLs of their systems in the usual manner prescribed in the NCC, e.g. reports from registered testing authorities. This applies to items such as:
• fire-protected timber (including additional information relating to incipient spread of fire and protection of massive timber substrates)
• cavity barriers
• service penetrations (including incipient spread of fire requirements in 2015 edition of AS 1530.4)
• fire doors
• lift landing doors.</td><td>Suppliers of proprietary engineered timber systems, such as lightweight timber trusses, CLT and coverings to be used for fire-protected timber systems, along with cavity barriers will be required to undertake fire resistance tests demonstrating the performance levels are met by the specific materials and methods of construction adopted for the systems.</td></tr>
</table>

Issue	Discussion	Outcome
16: How are the limitations of standard fire resistance test method/FRLs taken into account?	As part of this analysis, a review of lightweight timber and massive timber elements, enclosures and buildings subjected to standard fire resistance tests and natural fire experiments was undertaken. The results were compared using the correlation methods verified against experimental data to adjust the performance for differing heating rates, providing confidence in the application of fire resistance test data. The required use of fire-protected timber requires the use of fire protection systems commonly used to protect structural steel, providing consistency with current Deemed-to-Satisfy Provisions. In addition, methods were derived to model the additional contribution from timber elements if they are exposed directly to fire, for example, by premature failure of a covering.	Correlation methods have been developed to modify fire resistance test results to address issues such as variations in heating rates and adjust model inputs to account for increased fire severity due to exposure of timber members if coverings fail. These methods have been verified against natural fire data.
17: What will be the requirements for fire stairs?	Fire stairs will be required to be constructed of fire-protected timber (i.e. lined with non-combustible fire-protective coverings). The use of timber stairways will be permitted, subject to the extension of automatic fire sprinkler coverage to the fire-isolated stair and the protection of the underside of the stair on the ground level to address the risk of material storage (even though such activities are not permitted).	Fire-protected timber will be used for stair shafts (i.e. non-combustible fire-resistant linings). If timber stairways are to be fitted. the automatic fire sprinkler shall be extended to cover the stair and the underside of the stairs protected on the ground level.
18: How will evacuation of people with disabilities be managed?	The timber mid-rise building as described in the PFC will provide increased levels of safety because of the provision of an automatic fire sprinkler system, which will maintain tenable conditions throughout the fire exits and path of travel to fire exits for considerably longer than a building complying with the current NCC Deemed-to-Satisfy building, in most circumstances. This provides increased opportunity for the safe evacuation of people with disabilities. The modelling undertaken assumes some occupants will require assistance to evacuate, which inherently considers people with disabilities who may require assistance.	While specific approaches may vary between buildings, the requirement for automatic fire sprinklers will increase the time that tenable conditions are maintained in evacuation paths, greatly improving safety for people with disabilities.
19: What façade fire spread precautions will be required?	The external façade surface will be non-combustible. Fire-protected timber will be used, minimising the risk of the timber substrate being ignited and providing a similar level of protection to the current Deemed-to-Satisfy Provisions. In addition, automatic fire sprinklers are specified as are cavity barriers with minimum FRLs of –/45/45, further reducing the risk of fire spread via the façade.	The following combination of systems is specified which reduces the risk of fire spread via the building façade compared to the NCC Deemed-to-Satisfy requirements for the control building: • automatic fire sprinklers • fire-protected timber • cavity barriers.
20: Are any special maintenance requirements necessary for timber construction?	Normal maintenance Provisions should be adequate. These include • requirements to reinstate the fire resistance performance of fire-resistant barriers when new services are fitted • notifications when active fire safety measures are non-operational due to maintenance/service activities and reinstatement at the end of each working day • hot work permit systems, etc.	No changes are required above normal good practice standards. The analysis considered the performance of elements with defects, checking that the design is robust and outcomes are not disproportionate to the failure of elements

Issue	Discussion	Outcome
21: How is the potential increase in the consequences of fires during construction going to be addressed?	The potential increase in consequences from fires during construction is to be addressed through a holistic approach to safety, as outlined in WoodSolutions Technical Design Guide #20.	Publication of WoodSolutions Technical Design Guide #20: *Fire Precautions During Construction of Large Buildings.*
22: What will be the impact of fire-fighting water on a CLT building?	CLT buildings overseas have been subjected to wet weather conditions for significant periods during construction without significant detrimental effects. CLT structures are airtight structures. Glue lines act as barriers to moisture movement. Therefore, CLT construction will perform better than traditional construction methods in some instances.	Impact of fire-fighting water other than staining is expected to be minimal.
23: How is fire spread between buildings addressed?	The external façade surface will be non-combustible and fire-protected timber will be used, minimising the risk of the timber substrate being ignited by radiant heat from an adjacent building. The fire-protected timber also reduces the risk of the external façade being ignited by a fire within the building creating a larger heat source radiating to adjacent structures. In addition, the provision of an automatic fire sprinkler system will substantially reduce the risk of fire spread to adjacent buildings	The following combination of systems is specified which reduces the risk of fire spread via the building façade compared to the NCC Deemed-to-Satisfy requirements for the control building: • automatic fire sprinklers • fire-protected timber.
24: What is the performance of connections used in timber element construction at elevated temperatures and under load? **Literature would suggest that the complex degradation of timber could result in the loss of embedding strength of timber (critical for mechanical fastenings) at relatively low temperatures (approx. 80–120°C); likewise some adhesives can crystallize, losing significant bond strength, at similar temperatures. This could result in failure even with sprinkler activation.**	The requirements for fire-protected timber in the PFC include: • Coverings that prevent interface temperatures reaching 300°C for a minimum of 20 minutes in low fire load areas and 30 minutes in most areas of the building for massive timber construction with the fire-protected timber exposed to the AS 1530.4 standard heating regime. • Coverings that prevent interface temperatures reaching 250°C for a minimum of 45 minutes for timber-framed construction with the fire-protected timber exposed to the AS 1530.4 standard heating regime. • Requirements for fire-protected timber elements to achieve the FRLs specified in the NCC (for Class 2 and 3 typically 90 minutes structural adequacy for loadbearing elements and 60 minutes for non-loadbearing elements). The specification of the standard fire resistance test means that all systems including engineered timber products must be subjected to fire resistance tests and loadbearing members are required to be tested under load. Systems that are vulnerable to premature failure during the early stages of a fire would be screened by these tests. The supplementary specification of minimum levels of fire-protective coverings provides further confidence and elements with high levels of inherent fire resistance are also required to have these coverings applied. The coverings are to be non-combustible and have to achieve the required performance when exposed to a standard fire resistance test. The elements surface would not be expected to be exposed to elevated temperatures prior to activation of an automatic sprinkler, except for fires initiating within timber members and failure of the automatic fire sprinkler system. Both these scenarios are considered in the detailed analysis.	All fire-protected systems are required to have their performance determined by being subjected to the standard fire resistance test which will prevent poor performing systems being approved under the proposed DTS Provisions. Both coverings and automatic fire sprinklers have been specified to provide a robust solution and the analysis has considered failure of fire protection systems to check the proposed changes provide robust building solutions.

Issue	Discussion	Outcome
25: Is AS1530.4 a relevant test for determining fire resistance for timber construction elements? **Does the methodology or assessment criteria need review or amendment?** **The AS1530.4 test requires an external heat flux input to maintain a temperature within a furnace. However, traditional non-combustible elements would receive a controlled heat flux exposure to maintain the temperature profile, whereas combustible elements, which once ignited contribute to the furnace temperature, may require a reduced (and potentially unrealistic) external heat flux to maintain an equivalent temperature profile. The comparability of combustible and non-combustible element test results (FRLs) should be explicitly investigated. Furthermore, what is the failure point and are they comparable? Failure conditions of a block wall assembly will be significantly different to the failure conditions of timber elements.**	AS 1530.4 is the standard method specified in the NCC for determining the fire resistance of elements of construction including timber elements, and is similar to most international standards that serve the same purpose; therefore it has direct relevance. However, this does not mean that the test has no limitations and that any limitations should not be considered in the analysis, development or review of DTS Provisions in the NCC. In the context of the analysis being undertaken, the results of fire resistance tests are applied to enclosure fires which can be characterised as a time temperature relationship that will vary with the size of the enclosure, fire load, ventilation conditions and thermal properties of the bounding construction. With the likely types of fire load, they will be initially ventilation controlled. Peak temperatures will occur close to stoichiometric conditions. The time temperature regime specified in AS 1530.4 will represent some of the fire scenarios, but not all, and with modern plastics and building configurations much more rapid growth rates and high early temperatures can occur. When undertaking fire resistance test, the gas supply is adjusted to achieve the required heating regime and does not just vary if combustible materials are tested; for example, the thermal performance of the element is also critical with materials such as aerated concrete requiring substantially less fuel than normal weight concrete. Therefore, one of the main weaknesses is also a strength of AS 1530.4, in that it applies a standard heating regime by which to determine the performance of a broad range of systems – many of which have different sensitivities to heating rates. To address the above and other limitations the following approach was adopted and applied to all elements considered in the analysis: • Multiple fire scenarios were generated based on varying values for fire load, room size and ventilation conditions. • A procedure was developed to convert standard fire resistance times to scenario times based on a critical element. • This approach was verified against full-scale experiments including natural fire tests including specimens under load to ensure the results obtained would be reasonable. The same procedure was adopted for combustible and non-combustible elements used in the analysis. Mechanisms of failure do vary. For example, some types of masonry wall and steel-framed construction are much more sensitive to P-Δ effects resulting from differential heating than timber-framed construction. The spalling of concrete was ignored in the analysis, improving the potential performance of the control building used in the comparative analysis and hence yielding a conservative comparison.	The limitations of the test method were considered in the detailed analysis and taken account of in converting fire resistance periods to fire scenario times. Results were compared to a large number of natural fire experiments and alternative heating regimes, such as the hydrocarbon heating regime, to provide confidence in the results.

Issue	Discussion	Outcome
26: What are the consequences of involvement of the timber elements in a fire? **The degradation of timber due to elevated temperatures and combustion is an extremely complex process that is understood from a generic basis only (i.e. charring rate analysis, 1-D heat conduction analysis). The behaviour of the timber in a fire, and the subsequent impact on the total structure, is unknown in this size of building and requires further research and/or a very conservative design philosophy. The PFC seems to suggest that the consequences of a spreading fire in a timber building would result in similar conditions for fire fighters to that encountered in a building of non-combustible construction; however this inference is not validated or contextualised against time of localised or total structural failure.**	The detailed analysis has drawn on a number of international research studies in addition to studies undertaken in Australia, including the TF 2000 project undertaken in the UK. The TF 2000 project included a natural fire test on a full-scale 6 storey mid-rise timber-frame building. The outcomes of the project were used to confirm that mid-rise timber buildings can meet the functional requirements of the Building Regulations in the UK. Compared to the UK requirements, the PFC proposal for Australia requires higher fire resistance ratings for loadbearing elements and the provision of automatic fire sprinklers. Therefore, the detailed analysis has drawn on directly relevant research and has taken a very conservative design philosophy. The detailed analysis considers the risk of localised and global collapse.	The matters raised have been addressed as part of the detailed analysis as described in the discussion. The preliminary analysis did not discuss these matters in depth.
27: Are sprinkler systems in these buildings a mandatory component or are they subject to alternative solution? **The PFC suggests that sprinklers are essentially a layer of redundancy; however, the involvement of the timber elements in a fire is directly linked to flashover conditions being achieved. As sprinkler systems can control/suppress a fire to prevent the onset of flashover, sprinkler systems are now a critical aspect for maintaining structural adequacy. As detailed above, significant unknowns exist if the timber elements become involved in the fire, therefore sprinklers are essential to mitigate the risk of consequences associated with these unknowns.**	It is agreed that sprinkler systems are important and they are mandatory in the DTS solution put forward in the PFC. While the use of the term 'redundancy' is considered appropriate in a risk context, there have been some modifications in the wording used in the detailed analysis to indicate that sprinkler systems are a critical component.	The provision of automatic fire sprinklers is a critical element of the proposed DTS solution.
28: Is the current sprinkler standard, including reliability and maintenance, suitable given the potential structural consequences of sprinkler failure/ineffectiveness? **The PFC suggests that both lightweight timber-framed construction and massive timber building systems can be "protected" through similar passive fire protection covering. As these are two completely different systems with starkly different issues associated with elevated temperatures and combustion, this further highlights the criticality of sprinklers to ensure that the timber, regardless of construction method, does not become involved in the fire. The design, installation, and maintenance of the sprinkler system should reflect this to provide a very high reliability. However, it should be noted that simply the presence of sprinklers does not address the issues associated with the performance of timber building systems at relatively low elevated temperatures and fire spread in cavities.**	The analysis adopted a value for the reliability for automatic fire sprinklers of 92%, based on a literature review and stochastic analysis that considered the outcomes of scenarios where the automatic fire sprinklers may fail. Due to the conservative approach adopted, the net result of the probabilistic approach considering the reliability of sprinklers was a substantial improvement in life safety. Comments on the low temperature performance of elements is provided under item 25. The detailed analysis also addresses cavity fires in detail.	The analysis indicates that there will be a very large improvement in life safety using "current standard fire sprinkler systems" without enhancements, due to the large range of additional measures being adopted.

Issue	Discussion	Outcome
29: Do the NCC Deemed-to-Satisfy Provisions require the fire resistance of floor/ceiling systems to be evaluated from above? **If so, how is this addressed for mid-rise timber buildings?**	The NCC DTS Provisions require the FRL of elements of construction to be evaluated in accordance with the standard fire resistance test method AS 1530.4. In line with most international fire resistance test methods, AS 1530.4 does not require floor/ceiling systems to be evaluated when exposed to heating from above. Therefore, it can only be concluded that the NCC Deemed-to-Satisfy Provisions do not require floor/ceiling systems to achieve an FRL when exposed to fire conditions from above. There is one potential exception to this – Clause D2.11 – which under some circumstances requires the FRL of enclosing construction of fire-isolated passageways to be evaluated when exposed to fire from outside the passageway. Some regulators extend this requirement to enclosure of the top of fire-isolated stair shafts under Spec C1.1 Clause 2.7, under some circumstances. Cases of internal downward fire spread are relatively rare in buildings, which is assumed to be the basis for the NCC DTS Provisions to not require downward fire spread to be evaluated. If it were to be required to generally evaluate the fire resistance performance of floor and ceiling systems from above, the AS 1530.4 method will require modification and many existing construction systems will require modification to ensure, for example, critical fixings are not exposed and service penetrations systems also achieve the required FRL when exposed to fire from above and do not allow burning droplets to fall to the floor below. These issues are not as critical for the enclosure of fire-isolated stairs and passageways, where service penetrations are restricted and the roof of the enclosures tends to be similar to the wall construction. There are notable examples of external downward fire spread involving cladding systems with thermoplastic components that can facilitate downward fire spread by means of burning droplets/molten material. Timber does not exhibit this behaviour because it forms a char when exposed to heat. Notwithstanding the above, the mid-rise timber building Provisions introduced into the NCC address the risk of downward fire spread in a practical way through the specification of automatic fire sprinkler protection, which substantially reduces the risk of a fully developed fire and hence downward fire spread. In addition, the requirements for cavity barriers minimise the consequences should the sprinkler system fail and fire penetrate the floor/ceiling void from above (if a void is present) prior to fire brigade intervention.	The current NCC DTS Provisions do not require floor/ceiling systems to be resistant to fire spread from above (outside) except for some fire-isolated stair and passageway configurations. Notwithstanding the above, the mid-rise timber building Provisions introduced in the NCC 2016 mitigate the risk of downward fire spread through the specification of automatic fire sprinkler protection, which substantially reduces the risk of a fully developed fire and hence downward fire spread compared to other mid-rise forms of construction. Also, as a further redundancy, the requirements for cavity barriers will restrict lateral fire spread in the low probability of failure of the sprinkler system and occurrence of downward fire spread.

C Appendix C - Deemed-to-Satisfy Clauses from NCC 2015 Volume One Affected by the Introduction of a Mid-Rise Timber Building Solution in the 2016 Edition

Description	NCC clause	DTS Requirement	Comments
Non-combustible materials (concession)	C1.12	The following materials, though combustible or containing combustible fibres, may be used wherever a non-combustible material is required: (a) Plasterboard. (b) Perforated gypsum lath with a normal paper finish. (c) Fibrous-plaster sheet (d) Fibre-reinforced cement sheeting (e) Pre-finished metal sheeting having a combustible surface finish not exceeding 1 mm thickness and where the Spread-of-Flame Index of the product is not greater than 0. (f) Bonded laminated materials where - (i) each laminate is non-combustible; and (ii) each adhesive layer does not exceed 1 mm in thickness; and (iii) the total thickness of the adhesive layers does not exceed 2 mm; and (iv) the Spread-of-Flame Index and the Smoke-Developed Index of the laminated material as a whole does not exceed 0 and 3 respectively.	Additional Clause C1.13 applies to fire-protected timber.
Vertical Separation of openings	C2.6	(a) If in a building of Type A construction, any part of a window or other opening in an external wall is above another opening in the storey next below and its vertical projection falls no further than 450 mm outside the lower opening (measured horizontally), the openings must be separated by - (i) a spandrel which - (A) is not less than 900 mm in height; and (B) extends not less than 600 mm above the upper surface of the intervening floor; and (C) is of non-combustible material having an FRL of not less than 60/60/60; or (ii) part of a curtain wall or panel wall that complies with (i); or (iii) construction that complies with (i) behind a curtain wall or panel wall and has any gaps packed with a non-combustible material that will withstand thermal expansion and structural movement of the walling without the loss of seal against fire and smoke; or (iv) a slab or other horizontal construction that - (A) projects outwards from the external face of the wall not less than 1100 mm; and (B) extends along the wall not less than 450 mm beyond the openings concerned; and (C) is non-combustible and has an FRL of not less than 60/60/60. (b) The requirements of (a) do not apply to - (i) an open-deck carpark; or (ii) an open spectator stand; or (iii) a building which has a sprinkler system complying with Specification E1.5 installed throughout; or (iv) openings within the same stairway; or (v) openings in external walls where the floor separating the storeys does not require an FRL with respect to integrity and insulation. (c) For the purposes of C2.6, window or other opening means that part of the external wall of a building that does not have an FRL of 60/60/60 or greater.	An automatic fire sprinkler system complying with Specification E1.5 is to be installed throughout, so other requirements of this clause do not apply – refer clause 2.6(b). There is therefore no variation from this clause. Analysis showed the automatic fire sprinkler option reduces the risk to life.

Description	NCC clause	DTS Requirement	Comments
Separation by Fire Walls	C2.7	(a) Construction — A fire wall must be constructed in accordance with the following: (i) The fire wall has the relevant FRL prescribed by Specification C1.1 for each of the adjoining parts, and if these are different, the greater FRL, except where Tables 3.9, 4.2 and 5.2 of Specification C1.1 permit a lower FRL on the carpark side. (ii) Any openings in a fire wall must not reduce the FRL required by Specification C1.1 for the fire wall, except where permitted by the Deemed-to-Satisfy Provisions of Part C3. (iii) Building elements, other than roof battens with dimensions of 75 mm x 50 mm or less or sarking-type material, must not pass through or cross the fire wall unless the required fire resisting performance of the fire wall is maintained. (b) Separation of buildings — A part of a building separated from the remainder of the building by a fire wall may be treated as a separate building for the purposes of the Deemed-to-Satisfy Provisions of Sections C, D and E if it is constructed in accordance with (a) and the following: (i) The fire wall extends through all storeys and spaces in the nature of storeys that are common to that part and any adjoining part of the building. (ii) The fire wall is carried through to the underside of the roof covering. (iii) Where the roof of one of the adjoining parts is lower than the roof of the other part, the fire wall extends to the underside of— (A) the covering of the higher roof, or not less than 6 m above the covering of the lower roof; or (B) the lower roof if it has an FRL not less than that of the fire wall and no openings closer than 3 m to any wall above the lower roof; or (C) the lower roof if it's covering is non-combustible and the lower part has a sprinkler system complying with Specification E1.5. (c)Separation of fire compartments — A part of a building separated from the remainder of the building by a fire wall may be treated as a separate fire compartment if it is constructed in accordance with (a) and the fire wall extends to the underside of— (i) a floor having an FRL required for a fire wall; or (ii) the roof covering.	Loadbearing fire walls are currently required to be of masonry or concrete construction and therefore the proposed new clauses in Specification C1.1 Clause 3.1 and 4.1 will permit these walls to be manufactured from timber with fire-protective coverings. Fire-protective coverings and automatic fire sprinklers for buildings with an effective height limit of 25 m have been shown to substantially reduce the risk to occupants.
Separation of Classifications in the same storey	C2.8	If a building has parts of different classifications located alongside one another in the same storey— (a) each building element in that storey must have the higher FRL prescribed in Specification C1.1 for that element for the classifications concerned; or (b) the parts must be separated in that storey by a fire wall having— (i) the higher FRL prescribed in Table 3 or 4; or (ii) the FRL prescribed in Table 5, of Specification C1.1 as applicable, for that element for the Type of construction and the classifications concerned; or (c) where one part is a carpark complying with Table 3.9, 4.2 or 5.2 of Specification C1.1, the parts may be separated	Loadbearing fire walls are currently required to be of masonry or concrete construction. The proposed new clauses in Specification C1.1 Clause 3.1 and 4.1 will permit these walls to be manufactured from timber with fire-protective coverings. Fire-protective coverings and automatic fire sprinklers for buildings with an effective height limit of 25 m have been shown to substantially reduce the risk to occupants.

Description	NCC clause	DTS Requirement	Comments
Separation of lift shafts	C2.10	(a) Any lift connecting more than 2 storeys, or more than 3 storeys if the building is sprinklered, (other than lifts which are wholly within an atrium) must be separated from the remainder of the building by enclosure in a shaft in which— (i) in a building required to be of Type A construction—the walls have the relevant FRL prescribed by Specification C1.1; and (ii) in a building required to be of Type B construction — the walls— (A) if loadbearing, have the relevant FRL prescribed by Table 4 of Specification C1.1; or. (B) if non-loadbearing, be of non-combustible construction. (b) Any lift in a patient care area in a Class 9a health-care building or a resident use area in Class 9c aged care building must be separated from the remainder of the building by a shaft having an FRL of not less than— (i) in a building of Type A or B construction — 120/120/120; or (ii) in a building of Type C construction — 60/60/60. (c) An emergency lift must be contained within a fire-resisting shaft having an FRL of not less than 120/120/120. (d) Openings for lift landing doors and services must be protected in accordance with the Deemed-to-Satisfy Provisions of Part C3.	Tables 3 and 4 of Specification C1.1 require loadbearing lift shafts to have an FRL of 90/90/90 and non-loadbearing lift shafts to have an FRL of -/90/90 for Buildings of Type A and B construction, respectively. These will be satisfied. Clauses 3 and 4 of Specification C1.1 currently require – A non-loadbearing internal wall required to be fire resisting to be of non-combustible construction and a loadbearing internal wall (including those that are part of a loadbearing shaft) to be concrete or masonry. The proposed changes will allow the use of timber protected by fire-preventative coverings. Fire-protective coverings and automatic fire sprinklers for buildings with an effective height limit of 25 m have been shown to address any potential for increased risk associated with the changes.
Separation of Equipment	C2.12	(a) Equipment other than that described in (b) and (c) must be separated from the remainder of the building with construction complying with (d), if that equipment comprises— (i) lift motors and lift control panels; or (ii) emergency generators used to sustain emergency equipment operating in the emergency mode; or (iii) central smoke control plant; or (iv) boilers; or (v) a battery or batteries installed in the building that have a voltage exceeding 24 volts and a capacity exceeding 10 ampere hours. (b) Equipment need not be separated in accordance with (a) if the equipment comprises— (i) smoke control exhaust fans located in the air stream which are constructed for high temperature operation in accordance with Specification E2.2b; or (ii) stair pressurising equipment installed in compliance with the relevant provisions of AS/NZS 1668.1; or (iii) a lift installation without a machine-room; or (iv) equipment otherwise adequately separated from the remainder of the building. (c) Separation of on-site fire pumps must comply with the requirements of AS 2419.1. (d) Separating construction must have— (i) except as provided by (ii)— (A) an FRL as required by Specification C1.1, but not less than 120/120/120; and (B) any doorway protected with a self-closing fire door having an FRL of not less than –/120/30; or (ii) when separating a lift shaft and lift motor room, an FRL not less than 120/–/–.	C2.12 requires separation by construction having an FRL not less than 120/120/120. This will be satisfied. Clauses 3 and 4 of Specification C1.1 currently require – A non-loadbearing internal wall required to be fire resisting to be of non-combustible construction and a loadbearing internal wall (including those that are part of a loadbearing shaft) to be concrete or masonry. The proposed changes will allow the use of timber protected by fire-preventative coverings. The provision of fire-protective coverings and automatic fire sprinklers for buildings with an effective height limit of 25 m is expected to address any potential for increased risk associated with the changes.

Description	NCC clause	DTS Requirement	Comments
Electricity supply System	C2.13	(a) An electricity substation located within a building must— (i) be separated from any other part of the building by construction having an FRL of not less than 120/120/120; and (ii) have any doorway in that construction protected with a self-closing fire door having an FRL of not less than –/120/30. (b) A main switchboard located within the building which sustains emergency equipment operating in the emergency mode must— (i) be separated from any other part of the building by construction having an FRL of not less than 120/120/120; and (ii) have any doorway in that construction protected with a self-closing fire door having an FRL of not less than –/120/30. (c)Electrical conductors located within a building that supply— (i)a substation located within the building which supplies a main switchboard covered by (b); or (ii) a main switchboard covered by (b), must- (iii) have a classification in accordance with AS/NZS 3013 of not less than— (A) if located in a position that could be subject to damage by motor vehicles — WS53W; or (B) otherwise — WS52W; or (iv) be enclosed or otherwise protected by construction having an FRL of not less than 120/120/120. (d) Where emergency equipment is required in a building, all switchboards in the electrical installation, which sustain the electricity supply to the emergency equipment, must be constructed so that emergency equipment switchgear is separated from non-emergency equipment switchgear by metal partitions designed to minimise the spread of a fault from the non-emergency equipment switchgear. (e)For the purposes of (d), emergency equipment includes but is not limited to the following: (i) Fire hydrant booster pumps. (ii) Pumps for automatic sprinkler systems, water spray, chemical fluid suppression systems or the like. (iii) Pumps for fire hose reels where such pumps and fire hose reels form the sole means of fire protection in the building. (iv) Air handling systems designed to exhaust and control the spread of fire and smoke.	C2.13 requires separation by construction having an FRL of 120/120/120. This will be satisfied. Clauses 3 and 4 of Specification C1.1 currently require – A non-loadbearing internal wall required to be fire resisting to be of non-combustible construction and a loadbearing internal wall (including those that are part of a loadbearing shaft) to be concrete or masonry. The proposed changes will allow the use of timber protected by fire-preventative coverings. The provision of fire-protective coverings and automatic fire sprinklers for buildings with an effective height limit of 25 m is expected to address any potential for increased risk associated with the changes.
Public corridors in Class 2 and 3 buildings	C2.14	C2.14 Public corridors in Class 2 and 3 buildings In a Class 2 or 3 building, a public corridor, if more than 40 m in length, must be divided at intervals of not more than 40 m with smoke-proof walls complying with Clause 2 of Specification C2.5	This could be required for large Class 2 and 3 buildings and Clause 2 of Specification 2.5 specifies non-combustible construction. The provision of fire-protective coverings and fire sprinklers for buildings with an effective height limit of 25 m is expected to address any potential for increased risk.
Openings in floors and ceilings for services	C3.12	(a) Where a service passes through— (i) a floor that is required to have an FRL with respect to integrity and insulation; or (ii) a ceiling required to have a resistance to the incipient spread of fire, the service must be installed in accordance with (b). (b) A service must be protected— (i) in a building of Type A construction, by a shaft complying with Specification C1.1; or (ii) in a building of Type B or C construction, by a shaft that will not reduce the fire performance of the building elements it penetrates; or (iii) in accordance with C3.15. (c) Where a service passes through a floor which is required to be protected by a fire protective covering, the penetration must not reduce the fire performance of the covering.	Service penetrations protected by a shaft complying with Specification 1.1 would comply, except that timber-framed shafts lined with fire-resistant coverings would be permitted. Also, timber elements protected by coverings would be permitted within 100 mm of an uninsulated service penetration system complying with C3.15. The provision of fire-protective coverings and automatic fire sprinklers for buildings with an effective height limit of 25 m is expected to address any potential for increased risk associated with the changes.

Description	NCC clause	DTS Requirement	Comments
Openings for Service Installations	C3.15	Where an electrical, electronic, plumbing, mechanical ventilation, air-conditioning or other service penetrates a building element (other than an external wall or roof) that is required to have an FRL with respect to integrity or insulation or a resistance to the incipient spread of fire, that installation must comply with any one of the following: (a) Tested systems (i)The service, building element and any protection method at the penetration are identical with a prototype assembly of the service, building element and protection method which has been tested in accordance with AS 4072.1 and AS 1530.4 and has achieved the required FRL or resistance to the incipient spread of fire. (ii) It complies with (i) except for the insulation criteria relating to the service if— (A) the service is a pipe system comprised entirely of metal (excluding pipe seals or the like); and (B) any combustible building element is not located within 100 mm of the service for a distance of 2 m from the penetration; and (C) combustible material is not able to be located within 100 mm of the service for a distance of 2 m from the penetration; and (D) it is not located in a required exit. (b) Ventilation and air-conditioning — In the case of ventilating or air-conditioning ducts or equipment, the installation is in accordance with AS/NZS 1668.1. (c) Compliance with Specification C3.15 (i) The service is a pipe system comprised entirely of metal (excluding pipe seals or the like) and is installed in accordance with Specification C3.15 and it— (A) penetrates a wall, floor or ceiling, but not a ceiling required to have a resistance to the incipient spread of fire; and (B) connects not more than 2 fire compartments in addition to any fire-resisting service shafts; and (C) does not contain a flammable or combustible liquid or gas. (ii) The service is sanitary plumbing installed in accordance with Specification C3.15 and it— (A) is of metal or UPVC pipe; and (B) penetrates the floors of a Class 5, 6, 7, 8 or 9b building; and (C) is in a sanitary compartment separated from other parts of the building by walls with the FRL required by Specification C1.1 for a stair shaft in the building and a self-closing –/60/30 fire door. (iii) The service is a wire or cable, or a cluster of wires or cables installed in accordance with Specification C3.15 and it— (A) penetrates a wall, floor or ceiling, but not a ceiling required to have a resistance to the incipient spread of fire; and (B) connects not more than 2 fire compartments in addition to any fire-resisting service shafts. (iv) The service is an electrical switch, outlet, or the like, and it is installed in accordance with Specification C3.15.	Service penetrations to be protected in accordance with C3.15 to maintain fire separation. Reliance will be predominantly on tested/assessed systems. There is a slight relaxation, in that timber elements would be permitted within 100 mm of uninsulated service penetrations subject to the timber being protected by fire-protective coverings. The provision of fire-protective coverings and automatic fire sprinklers for buildings with an effective height limit of 25 m is expected to address any potential for increased risk associated with the changes.
Columns protected with lightweight construction to achieve an FRL	C3.17	A column protected by lightweight construction to achieve an FRL which passes through a building element that is required to have an FRL or a resistance to the incipient spread of fire, must be installed using a method and materials identical with a prototype assembly of the construction which has achieved the required FRL or resistance to the incipient spread of fire.	Fire-tested systems will be adopted and therefore this clause will be satisfied.

Description	NCC clause	DTS Requirement	Comments
General Concessions	Spec C1.1 Cl 2.5	(a) Steel columns — A steel column, other than one in a fire wall or common wall, need not have an FRL in a building that contains— (i) only 1 storey; or (ii) 2 storeys in some of its parts and 1 storey only in its remaining parts if the sum of the floor areas of the upper storeys of its 2 storey parts does not exceed the lesser of— (A) 1/8 of the sum of the floor areas of the 1 storey parts; or (B) in the case of a building to which one of the maximum floor areas specified in Table C2.2 is applicable — 1/10 of that area; or (C) in the case of a building to which two or more of the maximum floor areas specified in Table C2.2 is applicable — 1/10 of the lesser of those areas. (b) Timber columns — A timber column may be used in a single storey building if— (i) in a fire wall or common wall the column has an FRL not less than that listed in the appropriate Table 3, 4 or 5; and (ii) in any other case where the column is required to have an FRL in accordance with Table 3, 4 or 5, it has an FRL of not less than 30/–/–. (c) Structures on roofs — A non-combustible structure situated on a roof need not comply with the other provisions of this Specification if it only contains— (i) lift motor equipment; or (ii) one or more of the following: (A) Hot water or other water tanks. (B) Ventilating ductwork, ventilating fans and their motors. (C) Air-conditioning chillers. (D) Window cleaning equipment. (E) Other service units that are non-combustible and do not contain flammable or combustible liquids or gases. (d) Curtain walls and panel walls — A requirement for an external wall to have an FRL does not apply to a curtain wall or panel wall which is of non-combustible construction and fully protected by automatic external wall-wetting sprinklers. (e) * * * * * (f) Balconies and verandas — A balcony, veranda or the like and any incorporated supporting part, which is attached to or forms part of a building, need not comply with Tables 3, 4 and 5 if— (i) it does not form part of the only path of travel to a required exit from the building; and (ii) in Type A construction— (A) it is situated not more than 2 storeys above the lowest storey providing direct egress to a road or open space; and (B) any supporting columns are of non-combustible construction.	The proposed changes allow timber to be used in the applications where non-combustible construction is specified in these concessions (clauses d and e) subject to the use of fire-protected timber, the provision of automatic fire sprinklers throughout the building and with an effective height limit of 25 m. These precautions are expected to address any potential for increased risk associated with allowing the use of timber for these applications.
Enclosure of shafts	Spec C1.1 Cl 2.7	Shafts required to have an FRL must be enclosed at the top and bottom by construction having an FRL not less than that required for the walls of a non-loadbearing shaft in the same building, except that these provisions need not apply to— (a) the top of a shaft extending beyond the roof covering, other than one enclosing a fire-isolated stairway or ramp; or (b) the bottom of a shaft if it is non-combustible and laid directly on the ground.	FRLs will be in accordance with DTS at top and bottom of shafts. Fire-protected timber will be allowed for this application. In combination with the provision of automatic fire sprinklers, it is expected the changes will reduce the risk from fires.

Description	NCC clause	DTS Requirement	Comments
Residential aged Care Building	Spec C1.1 Cl 2.9	In a Class 3 building protected with a sprinkler system complying with Specification E1.5 and used as a residential aged care building, any FRL criterion prescribed in Tables 3, 4 or 5— (a) for any floor and any loadbearing wall, may be reduced to 60, except any FRL criterion of 90 for an external wall must be maintained when tested from the outside; and (b) for any non-loadbearing internal wall, need not apply if— (i) it is lined on each side with standard grade plasterboard not less than 13 mm thick or similar non-combustible material; and (ii) it extends— (A) to the underside of the floor next above; or (B) to the underside of a ceiling lined with standard grade plasterboard not less than 13 mm thick or a material with at least an equivalent level of fire protection; or (C) to the underside of a non-combustible roof covering; and (iii) any insulation installed in the cavity of the wall is non-combustible; and (iv) any construction joint, space or the like between the top of the wall and the floor, ceiling or roof is smoke sealed with intumescent putty or other suitable material.	This Clause relaxes the requirements for FRLs in Class 3 residential aged care buildings if protected by automatic fire sprinkler systems. The definition for fire-preventative coverings requires the element to achieve an FRL of 90/90/90 or -/90/90. Therefore, if timber with protective coverings is used in lieu of concrete, masonry or materials already Deemed-to-Satisfy non-combustible significantly higher FRLs will be provided, which would be expected to reduce the risk to life. This Clause does not apply to Class 2 buildings.
Type A Fire Resisting Construction	Spec C1.1 Cl 3.1	Fire-resistance of building elements In a building required to be of Type A construction— (a) each building element listed in Table 3 and any beam or column incorporated in it, must have an FRL not less than that listed in the Table for the particular Class of building concerned; and (b) external walls, common walls and the flooring and floor framing of lift pits must be non-combustible; and (c) any internal wall required to have an FRL with respect to integrity and insulation must extend to— (i) the underside of the floor next above; or (ii) the underside of a roof complying with Table 3; or (iii) if under Clause 3.5 the roof is not required to comply with Table 3, the underside of the non-combustible roof covering and, except for roof battens with dimensions of 75 mm x 50 mm or less or sarking-type material, must not be crossed by timber or other combustible building elements; or (iv) a ceiling that is immediately below the roof and has a resistance to the incipient spread of fire to the roof space between the ceiling and the roof of not less than 60 minutes; and (d) a loadbearing internal wall and a loadbearing fire wall (including those that are part of a loadbearing shaft) must be of concrete or masonry; and (e) a non-loadbearing— (i) internal wall required to be fire-resisting; and (ii) lift, ventilating, pipe, garbage, or similar shaft that is not for the discharge of hot products of combustion, must be of non-combustible construction; and (f) the FRLs specified in Table 3 for an external column apply also to those parts of an internal column that face and are within 1.5 m of a window and are exposed through that window to a fire-source feature.	The proposed changes allow fire-protected timber to be used, subject to the provision of automatic fire sprinklers throughout the building and an effective height limit of 25 m. These precautions are expected to address any potential for increased risk associated with allowing the use of timber for these applications. Clause 3.1(d) requires loadbearing internal and fire walls to be of masonry or concrete construction. The proposed new clause 3.1 will permit these walls to be manufactured from fire-protected timber subject to automatic fire sprinklers being provided and an effective height limit of 25 m applying, which is expected to address any potential for increased risk associated with the change.
Concessions for floors	Spec C1.1 Cl 3.2	A floor need not comply with Table 3 if— (a) it is laid directly on the ground; or (b) in a Class 2, 3, 5 or 9 building, the space below is not a storey, does not accommodate motor vehicles, is not a storage or work area, and is not used for any other ancillary purpose; or (c) it is a timber stage floor in a Class 9b building laid over a floor having the required FRL and the space below the stage is not used as a dressing room, store room, or the like; or (d) it is within a sole-occupancy unit in a Class 2 or 3 building or Class 4 part of a building; or (e) it is an open-access floor (for the accommodation of electrical and electronic services and the like) above a floor with the required FRL.	Will be applied as appropriate.

Description	NCC clause	DTS Requirement	Comments
Internal columns and walls: Concession	Spec C1.1 Cl 3.7	For a building with an effective height of not more than 25 m and having a roof without an FRL in accordance with Clause 3.5, in the storey immediately below that roof, internal columns other than those referred to in Clause 3.1(f) and internal walls other than fire walls and shaft walls may have— (a) in a Class 2 or 3 building: FRL 60/60/60; or (b) in a Class 5, 6, 7, 8 or 9 building— (i) with rise in storeys exceeding 3: FRL 60/60/60 (ii) with rise in storeys not exceeding 3: no FRL	If elements are also required to be non-combustible and fire protected timber is to be used, the FRLs of those members will be higher than those specified in this concession, tending to reduce the risk from fire
Type B Fire-Resisting Construction	Spec C1.1 Cl 4.1	In a building required to be of Type B construction— (a) each building element listed in Table 4, and any beam or column incorporated in it, must have an FRL not less than that listed in the Table for the particular Class of building concerned; and (b) the external walls, common walls, and the flooring and floor framing in any lift pit, must be non-combustible; and (c) if a stair shaft supports any floor or a structural part of it— (i) the floor or part must have an FRL of 60/–/– or more; or (ii) the junction of the stair shaft must be constructed so that the floor or part will be free to sag or fall in a fire without causing structural damage to the shaft; and (d) any internal wall which is required to have an FRL with respect to integrity and insulation, except a wall that bounds a sole-occupancy unit in the topmost (or only) storey and there is only one unit in that storey, must extend to— (i) the underside of the floor next above if that floor has an FRL of at least 30/30/30; or (ii) the underside of a ceiling having a resistance to the incipient spread of fire to the space above itself of not less than 60 minutes; or (iii) the underside of the roof covering if it is non-combustible and, except for roof battens with dimensions of 75 mm x 50 mm or less or sarking-type material, must not be crossed by timber or other combustible building elements; or (iv) 450 mm above the roof covering if it is combustible; and (e) a loadbearing internal wall and a loadbearing fire wall (including those that are part of a loadbearing shaft) must be of concrete or masonry; and (f) a non- loadbearing internal wall required to be fire-resisting must be of non-combustible construction; and (g) in a Class 5, 6, 7, 8 or 9 building, in the storey immediately below the roof, internal columns and internal walls other than fire walls and shaft walls, need not comply with Table 4; and (h) lift, subject to C2.10, ventilating, pipe, garbage, and similar shafts which are not for the discharge of hot products of combustion and not loadbearing, must be of non-combustible construction in— (i) a Class 2, 3 or 9 building; and (ii) a Class 5, 6, 7 or 8 building if the shaft connects more than 2 storeys; and (i) in a Class 2 or 3 building, except where within the one sole-occupancy unit, or a Class 9a health-care building or a Class 9b building, a floor separating storeys or above a space for the accommodation of motor vehicles or used for storage or any other ancillary purpose, must— (i) be constructed so that it is at least of the standard achieved by a floor/ceiling system incorporating a ceiling which has a resistance to the incipient spread of fire to the space above itself of not less than 60 minutes; or (ii) have an FRL of at least 30/30/30; or (iii) have a fire-protective covering on the underside of the floor, including beams incorporated in it, if the floor is combustible or of metal; and (j) in a Class 9c aged care building a floor above a space for the accommodation of motor vehicles or used for storage or any other ancillary purpose, and any column supporting the floor must— (i) be constructed so that it is at least of the standard achieved by a floor/ceiling system incorporating a ceiling which has a resistance to the incipient spread of fire to the space above itself of not less than 60 minutes; or (ii) have an FRL of at least 30/30/30; or (iii) have a fire-protective covering on the underside of the floor, including beams incorporated in it, if the floor is combustible or of metal.	The proposed changes allow fire-protected timber to be used in the applications where non-combustible construction is specified, subject to the provision of automatic fire sprinklers throughout the building and an effective height limit of 25 m (less for Type B construction). These precautions are expected to address any potential for increased risk associated with allowing the use of timber for these applications. Clause 4.1(e) requires loadbearing internal and fire walls to be of masonry or concrete construction. The proposed new clause 4.1 will permit these walls to be manufactured from fire-protected timber subject to the provision of automatic fire sprinklers and an effective height limit of 25 m, which is expected to address any potential for increased risk associated with the change.

Description	NCC clause	DTS Requirement	Comments
Smoke proof walls	Spec C2.5 Cl2	Class 9a health-care buildings Smoke-proof walls required by C2.5 in Class 9a health-care buildings must comply with the following: (a) Be non-combustible and extend to the underside of- (i) the floor above; or (ii) a non-combustible roof covering; or (iii) a ceiling having a resistance to the incipient spread of fire to the space above itself of not less than 60 minutes.	This clause also applies to Class 2 and 3 buildings via clause C2.14. For Class 2 and 3, the provision of protected timber and automatic fire sprinklers with an effective height limit of 25 m is expected to address any potential for increased risk associated with the changes.
Penetrations of walls floors and ceilings by services	Spec C3.15	1. Scope This Specification prescribes materials and methods of installation for services that penetrate walls, floors and ceilings required to have an FRL. 2. Application (a) This Specification applies to installations permitted under the Deemed-to-Satisfy Provisions of the NCC as alternatives to systems that have been demonstrated by test to fulfil the requirements of C3.15 (a). (b) This Specification does not apply to installations in ceilings required to have a resistance to the incipient spread of fire nor to the installation of piping that contains or is intended to contain a flammable liquid or gas. 3. Metal pipe systems (a) A pipe system comprised entirely of metal (excluding pipe seals or the like) that is not normally filled with liquid must not be located within 100 mm, for a distance of 2 m from the penetration, of any combustible building element or a position where combustible material may be located, and must be constructed of - (i) copper alloy or stainless steel with a wall thickness of at least 1 mm; or (ii) cast iron or steel (other than stainless steel) with a wall thickness of at least 2 mm. (b) An opening for a pipe system comprised entirely of metal (excluding pipe seals or the like) must - (i) be neatly formed, cut or drilled; and (ii) be no closer than 200 mm to any other service penetration; and (iii) accommodate only one pipe. (c) A pipe system comprised entirely of metal (excluding pipe seals or the like) must be wrapped but must not be lagged or enclosed in thermal insulation over the length of its penetration of a wall, floor or ceiling unless the lagging or thermal insulation fulfils the requirements of Clause 7. (d) The gap between a metal pipe and the wall, floor or ceiling it penetrates must be fire-stopped in accordance with Clause 7. 4. Pipes penetrating sanitary compartments If a pipe of metal or UPVC penetrates the floor of a sanitary compartment in accordance with C3.15(c)(ii) - (a) the opening must be neatly formed and no larger than is necessary to accommodate the pipe or fitting; and (b) the gap between pipe and floor must be fire-stopped in accordance with Clause 7. 5. Wires and cables If a wire or cable or cluster of wires or cables penetrates a floor, wall or ceiling— (a) the opening must be neatly formed, cut or drilled and no closer than 50 mm to any other service; and (b) the opening must be no larger in cross-sectional area than— (i) 2000 mm^2 if only a single cable is accommodated and the gap between cable and wall, floor or ceiling is no wider than 15 mm; or (ii) 500 mm^2 in any other case; and (c) the gap between the service and the wall, floor or ceiling must be fire-stopped in accordance with Clause 7.	There is a slight relaxation in that fire-protected timber would be permitted within 100 mm of uninsulated pipe penetrations, subject to the provision of automatic fire sprinklers for buildings with an effective height limit of 25 m. These requirements are expected to address any potential for increased risk associated with the change. It is noted that this specification is rarely used.

Description	NCC clause	DTS Requirement	Comments
Penetrations of walls floors and ceilings by services (continued)	Spec C3.15	6. Electrical switches and outlets If an electrical switch, outlet, socket or the like is accommodated in an opening or recess in a wall, floor or ceiling— (a) the opening or recess must not— (i) be located opposite any point within 300 mm horizontally or 600 mm vertically of any opening or recess on the opposite side of the wall; or (ii) extend beyond half the thickness of the wall; and (b) the gap between the service and the wall, floor or ceiling must be fire-stopped in accordance with Clause 7. 7. Fire-stopping (a) Material: The material used for the fire-stopping of service penetrations must be concrete, high-temperature mineral fibre, high-temperature ceramic fibre or other material that does not flow at a temperature below 1120°C when tested in accordance with ISO 540, and must have— (i) demonstrated in a system tested in accordance with C3.15(a) that it does not impair the fire-resisting performance of the building element in which it is installed; or (ii) demonstrated in a test in accordance with (e) that it does not impair the fire-resisting performance of the test slab. (b) Installation: Fire-stopping material must be packed into the gap between the service and wall, floor or ceiling in a manner, and compressed to the same degree, as adopted for testing under Clause 7(a) (i) or (ii). (c) Hollow construction: If a pipe penetrates a hollow wall (such as a stud wall, a cavity wall or a wall of hollow blockwork) or a hollow floor/ceiling system, the cavity must be so framed and packed with fire-stopping material that is— (i) installed in accordance with Clause 7(b) to a thickness of 25 mm all-round the service for the full length of the penetration; and (ii) restrained, independently of the service, from moving or parting from the surfaces of the service and of the wall, floor or ceiling. (d) Recesses: If an electrical switch, socket, outlet or the like is accommodated in a recess in a hollow wall or hollow floor/ceiling system— (i) the cavity immediately behind the service must be framed and packed with fire-stopping material in accordance with Clause 7(c); or (ii) the back and sides of the service must be protected with refractory lining board identical with and to the same thickness as that in which the service is installed. (e) Test: The test to demonstrate compliance of a fire-stopping material with this Specification must be conducted as follows: (i) The test specimen must comprise a concrete slab not less than 1 m square and not more than 100 mm thick, and appropriately reinforced if necessary for structural adequacy during manufacture, transport and testing. (ii) The slab must have a hole 50 mm in diameter through the centre and the hole must be packed with the fire-stopping material. (iii) The slab must be conditioned in accordance with AS 1530.4. (iv) Two thermocouples complying with AS 1530.4 must be attached to the upper surface of the packing each about 5 mm from its centre. (v) The slab must be tested on flat generally in accordance with Section 10 of AS 1530.4 and must achieve an FRL of 60/60/60 or as otherwise required.	
External stairways or ramps in lieu of fire- isolated exits	D1.8	External stairways or ramps in lieu of fire-isolated exits (a) An external stairway or ramp may serve as a required exit in lieu of a fire-isolated exit serving a storey below an effective height of 25 m, if the stairway or ramp is- (i) non-combustible throughout; and (ii) protected in accordance with (c) if it is within 6 m of, and exposed to any part of the external wall of the building it serves.	Fire-protected timber would probably be impractical. However, if this approach was implemented, the coverings would be expected to address any increased risk associated with the use of timber.

Description	NCC clause	DTS Requirement	Comments
Fire-isolated stairways and ramps	D2.2	Fire-isolated stairways and ramps A stairway or ramp (including any landings) that is required to be within a fire-resisting shaft must be constructed- (a) of non-combustible materials; and (b) so that if there is local failure it will not cause structural damage to, or impair the fire-resistance of, the shaft.	Fire-protected timber would probably be impractical. However, if this approach was implemented, the coverings would be expected to address any increased risk associated with the use of timber
Non-fire-isolated stairways and ramps	D2.4	Separation of rising and descending stair flights If a stairway serving as an exit is required to be fire-isolated- (a) there must be no direct connection between- (i) a flight rising from a storey below the lowest level of access to a road or open space; and (ii) a flight descending from a storey above that level; and (b) any construction that separates or is common to the rising and descending flights must be- (i) non-combustible; and (ii) smoke-proof in accordance with Clause 2 of Specification C2.S.	Fire-protected timber would be expected to address any increased risk associated with the use of timber
	D2.7	Installations in exits and paths of travel (a) Access to service shafts and services other than to fire-fighting or detection equipment as permitted in the Deemed-to-Satisfy Provisions of Section E, must not be provided from a fire-isolated stairway, fire-isolated passageway or fire isolated ramp. (b) An opening to any chute or duct intended to convey hot products of combustion from a boiler, incinerator, fireplace or the like, must not be located in any part of a required exit or any corridor, hallway, lobby or the like leading to a required exit. (c) Gas or other fuel services must not be installed in a required exit. (d) Services or equipment comprising- (i) electricity meters, distribution boards or ducts; or (ii) central telecommunications distribution boards or equipment; or (iii) electrical motors or other motors serving equipment in the building, may be installed in- (iv) a required exit, except for fire-isolated exits specified in (a); or (v) in any corridor, hallway, lobby or the like leading to a required exit, if the services or equipment are enclosed by non-combustible construction or a fire protective covering with doorways or openings suitably sealed against smoke spreading from the enclosure.	Fire-protected timber would be expected to address any increased risk associated with the use of timber if the non-combustible construction option is selected.
	D2.11	Fire-isolated passageways (a) The enclosing construction of a fire-isolated passageway must have an FRL when tested for a fire outside the passageway in another part of the building of- (i) if the passageway discharges from a fire-isolated stairway or ramp – not less than that required for the stairway or ramp shaft; or (ii) in any other case - not less than 60/60/60. (b) Notwithstanding (a){ii), the top construction of a fire-isolated passageway need not have an FRL if the walls of the fire-isolated passageway extend to the underside of- (i) a non-combustible roof covering; or (ii) a ceiling having a resistance to the incipient spread of fire of not less than 60 minutes separating the roof space or ceiling space in all areas surrounding the passageway within the fire compartment.	No specific requirement for non-combustible construction.

D

Appendix D - Performance Requirement Review

D1 Directly Relevant Performance Requirements

The NCC performance requirements directly relevant to the changes to the NCC 2015 Deemed-to-Satisfy (DtS) Provisions to permit Class 2, 3 and 5 mid-rise timber buildings are listed below:

CP1

A building must have elements which will, to the degree necessary, maintain structural stability during a fire appropriate to –

(a) the function or use of the building; and
(b) the fire load; and
(c) the potential fire intensity; and
(d) the fire hazard; and
(e) the height of the building; and
(f) its proximity to other property; and
(g) any active fire safety systems installed in the building; and
(h) the size of any fire compartment; and
(i) fire brigade intervention; and
(j) other elements they support; and
(k) the evacuation time.

CP2

(a) A building must have elements which will, to the degree necessary, avoid the spread of fire –
(i) to exits; and
(ii) to sole-occupancy units and public corridors; and

Application:
CP2(a)(ii) only applies to a Class 2 or 3 building or Class 4 part of a building.
(iii) between buildings; and
(iv) in a building.

(b) Avoidance of the spread of fire referred to in (a) must be appropriate to –
(i) the function or use of the building; and
(ii) the fire load; and
(iii) the potential fire intensity; and
(iv) the fire hazard; and
(v) the number of storeys in the building; and
(vi) its proximity to other property; and
(vii) any active fire safety systems installed in the building; and
(viii) the size of any fire compartment; and
(ix) fire brigade intervention; and
(x) other elements they support; and
(xi) the evacuation time.

CP4

To maintain tenable conditions during occupant evacuation, a material and an assembly must, to the degree necessary, resist the spread of fire and limit the generation of smoke and heat, and any toxic gases likely to be produced, appropriate to –

(a) the evacuation time; and
(b) the number, mobility and other characteristics of occupants; and
(c) the function or use of the building; and
(d) any active fire safety systems installed in the building.

Application:
CP4 applies to linings, materials and assemblies in a Class 2 to 9 building.

CP6

A building must have elements, which will, to the degree necessary, avoid the spread of fire from service equipment having –

(a) a high fire hazard; or
(b) a potential for explosion resulting from a high fire hazard.

CP7

A building must have elements, which will, to the degree necessary, avoid the spread of fire so that emergency equipment provided in a building will continue to operate for a period of time necessary to ensure that the intended function of the equipment is maintained during a fire.

DP5

To protect evacuating occupants from a fire in the building exits must be fire-isolated, to the degree necessary, appropriate to –

(a) the number of storeys connected by the exits; and
(b) the fire safety system installed in the building; and
(c) the function or use of the building; and
(d) the number of storeys passed through by the exits; and
(e) fire brigade intervention.

EP1.4

An automatic fire suppression system must be installed to the degree necessary to control the development and spread of fire appropriate to –

(a) the size of the fire compartment; and
(b) the function or use of the building; and
(c) the fire hazard; and
(d) the height of the building.

EP2.2

(a) In the event of a fire in a building the conditions in any evacuation route must be maintained for the period of time occupants take to evacuate the part of the building so that –

(i) the temperature will not endanger human life; and
(ii) the level of visibility will enable the evacuation route to be determined; and
(iii) the level of toxicity will not endanger human life.

(b) The period of time occupants take to evacuate referred to in (a) must be appropriate to –

(i) the number, mobility and other characteristics of the occupants;
(ii) and the function or use of the building; and
(iii) the travel distance and other characteristics of the building; and
(iv) the fire load; and
(v) the potential fire intensity; and
(vi) the fire hazard; and
(vii) any active fire safety systems installed in the building; and
(viii) fire brigade intervention.

Limitation: EP2.2 does not apply to an open-deck car park or open spectator stand.

D2 Parameters for Consideration

The Parameters for consideration for the directly relevant performance requirements are summarized in Table D1 and a brief description of how they have been considered in the detailed analysis is provided following the table:

Table D1: Summary of parameters for consideration.

Parameters for Consideration	Performance Requirements							
	CP1 – A building must have elements which will, to the degree necessary, maintain structural stability during a fire.	CP2 – A building must have elements to avoid the spread of fire (i) to exits; (ii) to sole-occupancy units and public corridors; (iii) between buildings; and (iv) in a building.	CP4 – To maintain tenable conditions during occupant evacuation a material or assembly must, resist the spread of fire and limit the generation of smoke and heat, and any toxic gases likely to be produced…	CP6 – A building must have elements which will, to the degree necessary, avoid the spread of fire from service equipment…	CP7 – A building must have elements which will, to the degree necessary, avoid spread of fire so that emergency equipment will continue to operate for a period of time necessary to ensure that the intended function of the equipment is maintained during a fire.	DP5 – To protect evacuating occupants from a fire in the building, exits must be fire-isolated, to the degree necessary, appropriate to…	EP1.4 – An automatic fire suppression system to control the development and spread of fire appropriate to…	EP2.2 – …conditions in any evacuation route must be maintained for the period of time occupants take to evacuate the part of the building…
Function or use of building	●	●	●			●	●	●
Fire load	●	●						●
Potential fire intensity	●	●						●
Fire hazard	●	●		●			●	●
Height of building/ No. of storeys	●	●				●	●	
Proximity to other property	●	●						
Active fire safety systems	●	●	●					●
Size of fire compartment	●	●					●	
Fire brigade intervention	●	●				●		●
Other elements supported	●	●						
Evacuation time/travel distance	●	●	●					●
Occupant mobility, No. and characteristics			●					●
Building fire safety system					●	●		

Function and Use of the Building: The function and use of the building were considered in defining the building layouts and key inputs including derivation of fire loads, occupant numbers and characteristics ventilation conditions, etc.

Fire Load: This was derived based on a literature review and was used as one of the inputs to determine the fire intensity and duration.

Potential fire severity: This was calculated using the methods based on distributions derived for fire load, ventilation conditions and size of compartment together with lining properties. A multi-scenario analysis was adopted to cover a representative range of inputs.

Fire hazards: A review of fire data and literature together with discussions with relevant stakeholders was undertaken to ensure relevant fire hazards/scenarios were considered.

The impact of the height of the building/no of storeys: This was considered specifically when considering the impact of fire brigade intervention and the evacuation of occupants and inherently when estimating the consequences of fires.

Proximity to other buildings: This was addressed when considering the risk of fire spread between buildings.

Active fire safety Systems: The effectiveness of the fire detection and alarm system and automatic fire sprinklers was considered in the analysis.

Size of the compartments: This was a key input to determine the fire severity and also affected occupant numbers/evacuation and fire brigade intervention estimates for search and rescue activities.

Fire Brigade Intervention: A detailed multi-scenario analysis of fire brigade intervention was undertaken to consider the expected range of fire brigade intervention response and activity times.

Other elements supported: The analysis considered the global behaviour of the structures as far as practicable for a generic building and considered design to prevent disproportionate collapse (to be addressed through a separate FWPA Guide). The impact of fire spread through cavities was specifically addressed in relation to the risk of disproportionate collapse and hence other elements supported.

Evacuation time/travel distances: These were incorporated in the estimate of occupant evacuation including consideration of the impact of occupants encountering smoke during the evacuation process.

Occupant mobility, number and characteristics: The detailed analysis incorporated a stochastic evacuation model with distributions relating to the time to commence evacuation and the number of occupants, taking into account occupant characteristics which were compared to fire incidents and drills. The model incorporated a proportion of occupants who did not respond and evacuate unless assisted by the fire brigade.

Building fire safety system: The holistic building fire safety system was considered within the multi-scenario building analysis.

D3 Other Relevant (Supplementary) Performance Requirements

CP8 Any building element provided to resist the spread of fire must be protected, to the degree necessary, so that an adequate level of performance is maintained –

(a) where openings, construction joints and the like occur; and
(b) where penetrations occur for building services.

How CP8 was addressed – Analysis assumed that all service penetrations are protected in accordance with the NCC DTS Provisions for both the control and subject building, but the impact of defects was considered by allocating distributions around the mean FRL of a separating element.

CP9 Access must be provided to and around a building, to the degree necessary, for fire brigade vehicles and personnel to facilitate fire brigade intervention appropriate to –

(a) the function or use of the building; and
(b) the fire load; and
(c) the potential fire intensity; and
(d) the fire hazard; and
(e) any active fire safety systems installed in the building; and
(f) the size of any fire compartment.

How CP9 was addressed – Analysis assumed the same levels of access for both the control and subject building.

DP4 Exits must be provided from a building to allow occupants to evacuate safely, with their number, location and dimensions being appropriate to –

(a) the travel distance; and
(b) the number, mobility and other characteristics of occupants; and
(c) the function or use of the building; and
(d) the height of the building; and
(e) whether the exit is from above or below ground level.

How DP4 was addressed – Analysis assumed the same DtS-compliant configuration for both the control and subject building.

DP6 So that occupants can safely evacuate the building, paths of travel to exits must have dimensions appropriate to –

(a) the number, mobility and other characteristics of occupants; and
(b) the function or use of the building.

Limitation: DP6 does not apply to the internal parts of a sole-occupancy unit in a Class 2 or 3 building or Class 4 part of a building.

How DP6 was addressed - Analysis assumed the same DTS compliant configuration for both the control and subject buildings.

EP1.1 A fire hose reel system must be installed to the degree necessary to allow occupants to safely undertake initial attack on a fire appropriate to –

(a) the size of the fire compartment; and
(b) the function or use of the building; and
(c) any other fire safety systems installed in the building; and
(d) the fire hazard.

How EP1.1 was addressed – Analysis assumed the same DTS-compliant provisions for both the control and subject building and impact of manual fire-fighting by occupants and proportion of potential flashover fires derived from statistics will inherently take this into account. The NCC does not require fire hose reels in Class 2 and 3 buildings.

EP1.2 Fire extinguishers must be installed to the degree necessary to allow occupants to undertake initial attack on a fire appropriate to –

(a) the function or use of the building; and
(b) any other fire safety systems installed in the building; and
(c) the fire hazard.

How EP1.2 was addressed – Analysis assumed the same DTS-compliant provisions for both the control and subject building and impact of manual fire-fighting by occupants and proportion of potential flashover fires derived from statistics will inherently take this into account.

EP1.3 A fire hydrant system must be provided to the degree necessary to facilitate the needs of the fire brigade appropriate to –

(a) fire-fighting operations; and
(b) the floor area of the building; and
(c) the fire hazard.

Application: EP1.3 only applies to a building where a fire brigade is available to attend.

How EP1.3 was addressed – Analysis assumed the same DTS-compliant provisions for both the control and subject building and fire brigade intervention modelling will take these Provisions into account.

EP1.5 Suitable means of fire-fighting must be installed to the degree necessary in a building under construction to allow initial fire attack by construction workers and for the fire brigade to undertake attack on the fire appropriate to –

(a) the fire hazard; and
(b)the height the building has reached during its construction.

How EP1.5 was addressed – No relaxation to the DTS Provisions was sought. A broader approach to fire safety during construction is required to be taken to comply with WHS legislation normally requiring the development of a Fire Safety Plan with much broader scope than the NCC. Use of the WoodSolutions Technical Design Guide #20: Fire Precautions during Construction of Large Buildings is recommended for all buildings to supplement the NCC Deemed-to-Satisfy requirements

EP1.6 Suitable facilities must be provided to the degree necessary in a building to co-ordinate fire brigade intervention during an emergency appropriate to –

(a) the function or use of the building; and
(b) the floor area of the building; and
(c) the height of the building

How EP1.6 was addressed – Analysis assumed the same DTS-compliant provisions for both the control and subject building and fire brigade intervention modelling will take these provisions into account. Since the building is less than 25 m high, it will be assumed that these facilities will be limited to a Fire Indicator Panel close to the entrance.

EP2.1 In a building providing sleeping accommodation, occupants must be provided with automatic warning on the detection of smoke so they may evacuate in the event of a fire to a safe place.

Application: EP2.1 only applies to a Class 2, 3, 9a or 9c building or Class 4 part of a building.

How EP2.1 was addressed – Analysis assumed the same DTS-compliant provisions for both the control and subject building except that an additional alarm will be raised in the subject building upon activation of an automatic fire sprinkler system.

BP1.1

(a) A building or structure, during construction and use, with appropriate degrees of reliability must –

(i) perform adequately under all reasonably expected design actions; and

(ii) withstand extreme or frequently repeated design actions; and

(iii) be designed to sustain local damage, with the structural system as a whole remaining stable and not being damaged to an extent disproportionate to the original local damage; and

(iv) avoid causing damage to other properties, by resisting the actions to which it may reasonably expect to be subjected.

(b) The actions to be considered to satisfy (a) include but are not limited to –

(i) permanent actions (dead loads); and
(ii) imposed actions (live loads arising from occupancy and use); and
(iii) wind action; and
(iv) earthquake action; and
(v) snow action; and
(vi) liquid pressure action; and
(vii) ground water action; and
(viii) rainwater action (including ponding action); and
(ix) earth pressure action; and
(x) differential movement; and
(xi) time dependent effects (including creep and shrinkage); and
(xii) thermal effects; and
(xiii) ground movement caused by –

(A) swelling, shrinkage or freezing of the subsoil; and
(B) landslip or subsidence; and
(C) site works associated with the building or structure; and

(xiv) construction activity actions; and
(xv) termite actions.

How BP1.1 was addressed – It was assumed that the structure of the control and subject buildings will be designed in accordance with these provisions and specifically resistance to disproportionate collapse will be considered when considering the impact of a fully developed fire on the structures as required to show compliance with CP1.

E

Refer to NCC Spec A2.3 for FRL

Refer to NCC Spec A2.5 for RISF

Refer to NCC Spec A2.2 for non- combustibility

Refer to NCC Spec C1.13 for cavity barriers

Appendix E: Evidence of Suitability for Fire-protected Timber & Cavity Barriers

There are three components to the performance of fire-protected timber; all of which need to be satisfied:

- Fire-protective coverings must be non-combustible.
- The protected element must achieve the required fire resistance level – FRL.
- The protected element must achieve the required Resistance to the Incipient Spread of Fire (RISF).

E1 Non-combustible Fire-protective Covering

The NCC definition of non-combustible applies which states:

Non-combustible means –

(a) applied to a material – not deemed combustible as determined by AS 1530.1 – Combustibility Tests for Materials; and

(b) applied to construction or part of a building – constructed wholly of materials that are not deemed combustible.

This means that if the fire-protective covering is a composite or multi-layer system, each layer must be non-combustible. It is not acceptable to undertake a single combustibility test on the composite or just the facing materials and claim the fire-protective covering is non-combustible.

Typical examples of multi-layer systems are shown in Figure E1.

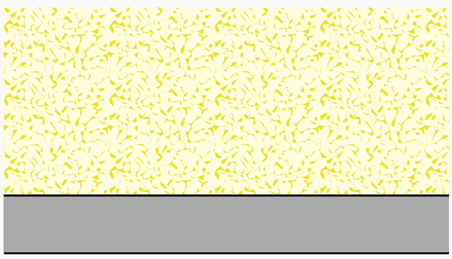
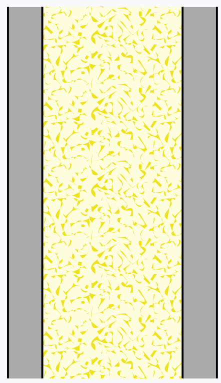
	
Multilayer –system – each layer must be non-combustible	Composite panels – each layer of the composite must be non-combustible
Commonly fire resistant board supporting non-combustible lightweight insulation used in ceilings protecting floors / beams	Commonly – non-combustible lightweight insulating core between non-combustible durable facings used for external claddings

Figure E1: Example of multi-layered fire-protective coverings (all layers).

In addition, Clause C1.12 of the NCC allows the following materials, though combustible or containing combustible fibres, to be used wherever a non-combustible material is required:

a) Plasterboard

b) Perforated gypsum lath with a normal paper finish

c) Fibrous-plaster sheet

d Fibre-reinforced cement sheeting

e) Pre-finished metal sheeting having a combustible surface finish not exceeding 1 mm thickness and where the Spread-of-Flame Index of the product is not greater than 0

f) Bonded laminated materials where –

i. each laminate is non-combustible; and

ii. each adhesive layer does not exceed 1 mm in thickness; and

iii. the total thickness of the adhesive layers does not exceed 2 mm; and

iv. the Spread-of-Flame Index and the Smoke-Developed Index of the laminated material as a whole does not exceed 0 and 3 respectively.

All materials forming the fire-protective covering shall therefore either be permitted to be used in accordance with NCC Clause C1.12 or shall be determined to be non-combustible by testing to AS1530.1.

E2 Fire Resistance Level

A fire-protected timber element must achieve the required FRL specified in the NCC for the particular application. The fire resistance of a fire-protected timber element has to be determined in accordance with Specification A 2.3 of the NCC.

Generally, Specification A2.3 requires a prototype to be submitted to the Standard Fire Test (AS1530.4) – or an equivalent or more severe test – and the FRL achieved by the prototype, without the assistance of an active fire suppression system, is confirmed in a report from a Registered Testing Authority (RTA) that:

(i) describes the method and conditions of the test and the form of construction of the tested prototype in full; and

(ii) certifies that the application of restraint to the prototype complied with the Standard Fire Test;

or

it differs in only a minor degree from a tested prototype and the FRL attributed to the building element is confirmed in a report from an RTA that –

(i) certifies that the building element is capable of achieving the FRL despite the minor departures from the tested prototype; and

(ii) describes the materials, construction and conditions of restraint which are necessary to achieve the FRL.

The option to use AS 1720.4(1990 and 2006 edition) char-based calculation methods without additional supporting data to determine the fire resistance of fire-protected timber is not appropriate. This is due to concerns regarding the suitability of the current AS 1720.4 approach for certain types of adhesives and connections forming parts of engineered timber products, and there was insufficient data available at the time to demonstrate the suitability or otherwise of AS 1720.4.

Figure E2 through Figure E4 show a fire resistance test performed on a lightweight timber floor/ceiling system incorporating a range of lightweight engineered timber joists and trusses protected by a fire-grade plasterboard ceiling.

Figure E2: Lightweight loaded timber floor system after 90-minute fire-resistance test.

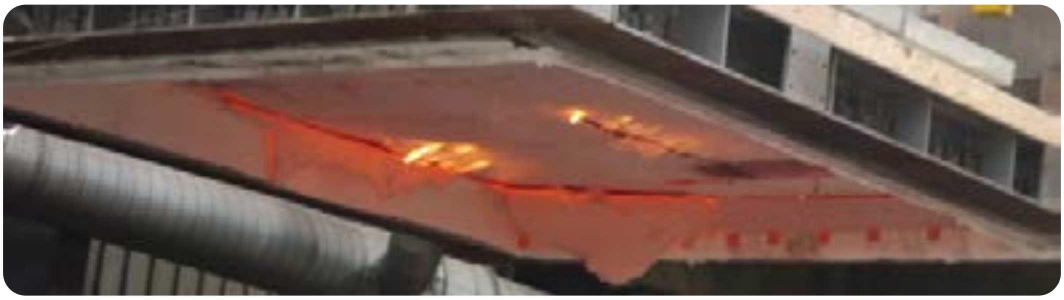


Figure E3: Fire-exposed face of lightweight loaded timber floor system after 90-minute fire resistance test.

Figure E4: Fire-exposed face of lightweight loaded timber floor system about eight minutes after 90-minute fire resistance test, after suppression with a fire hose.

E3 Resistance to the Incipient Spread of Fire

E3.1 Determine Applicable Resistance to Incipient Spread of Fire Requirements

The Resistance to the Incipient Spread of Fire (RISF) in relation to a fire-protective covering means the ability of the covering to insulate voids and the interfaces with timber elements so as to limit the temperature rise to a level that will not permit ignition of the timber and the rapid and general spread of fire throughout any concealed spaces. The performance is expressed as the period in minutes that the covering will maintain a temperature below the specified limits when subjected to a test in accordance with AS 1530.4.

The general requirement for fire-protected timber is an RISF of 45 minutes.

The NCC permits a relaxation to the resistance to incipient spread of fire requirements for massive timber panels providing both the following additional criteria are satisfied:

- The minimum timber thickness is not less than 75 mm.
- There are no cavities between the surface of the timber and the fire-protective covering or between timber members.

The 75 mm dimensions relate to the minimum dimensions of the dressed/finished timber member. If the relaxation conditions are satisfied then the modified resistance to incipient spread of fire (MRISF) criteria are applicable. Typical examples of massive timber installations satisfying the conditions for this concession to apply are shown in Figure 4.3 in the body of this Guide.

The flow chart in Figure E5 shows the process for determining the applicable RISF requirements.

The general requirement for fire-protected timber is an RISF of 45 minutes.

The relaxed requirements for massive timber construction without voids and cavities is an MRISF that applies a higher cavity temperature limit and the time periods for which the temperature limit applies varies according to the application in accordance with Table E1.

Table E1: MRISF for massive timber construction.

Application	Modified Resistance to Incipient Spread of Fire (MRISF)
Inside a fire-isolated stairway or lift shaft	20 min
External walls within 1 m of an allotment boundary or 2 m of a building on the same allotment	45 min
All other applications	30 min

Note: These criteria only apply if the massive timber element has a minimum thickness of 75 mm or greater and the form of construction does not include voids and cavities

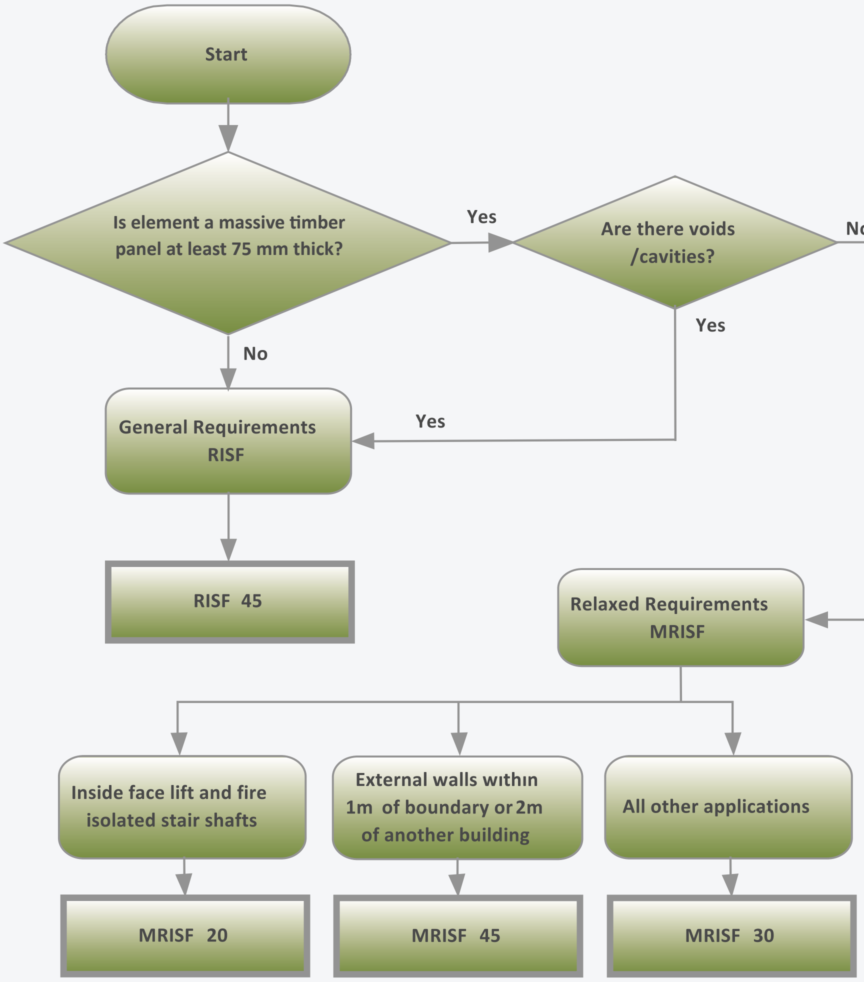


Figure E5: Determination of RISF acceptance requirements.

E3.2 Compliance Paths for Resistance to the Incipient Spread of Fire

Three paths are permitted to demonstrate compliance with the Resistance to the Incipient Spread of Fire requirements:

- simultaneous determination during a full-scale fire resistance test
- smaller scale fire resistance test (at least 1 m x 1 m specimen)
- selection of Deemed-to-Satisfy fire-resisting grade plasterboard coverings.

Simultaneous determination during a full-scale fire resistance test

When a fire resistance test is undertaken to determine the FRL of an element, additional instrumentation can be included in the test to also determine the RISF or MRISF performance – providing a cost-effective approach for new protection systems.

Smaller-scale fire resistance test

There are a large number of systems that have been tested previously to determine the FRLs, but in most cases insufficient data will have been recorded to determine the RISF or MRISF performance. Under these circumstances, the use of a smaller specimen (not less than 1 m x 1 m) is permitted to obtain supplementary data to determine the RISF or MRISF of the system in a cost-effective manner. The fire-protective covering should be fitted in the same manner as that used for the original test that determined the FRL of the system.

Deemed-to-Satisfy fire-protective-grade plasterboard coverings

Specification A1.1 deems fire-protective-grade plasterboard facings, if fixed in accordance with the requirements to achieve the required FRL of the element, to also satisfy the requirements for RISF with the performance as listed in Table E2.

Table E2: Minimum fire-protective-grade plasterboard coverings.

Requirements	Application	Performance	Minimum Deemed-to-Satisfy fire-protective-grade plasterboard
General Requirements	All applications	RISF 45min	2 layers x 13 mm thick
Relaxed requirements for timber elements not less than 75 mm x 75 mm without cavities voids or cavities voids filled with non-combustible material	Inside a fire-isolated stairway or lift shaft	MRISF 20 min	1 layer x 13 mm thick
	External walls within 1 m of an allotment boundary or 2 m of a building on the same allotment	MRISF 45 min	2 layers x 13 mm thick
	All other applications	MRIFS 30 min	1 layer x 16 mm thick

E3.3 Resistance to Incipient Spread of Fire (RISF) Test Procedures

The test procedure for determining the incipient spread of fire of horizontal elements during a full-scale fire resistance test is provided in Section 4 of AS 1530.4. Specification A1.1 of the NCC requires the relevant procedures from AS 1530.4 Section 4 to be applied to other elements.

AS 1530.4 requires walls to be full size or not less than 3 m high x 3 m wide, and floor/ceiling systems to be full size or not less than 4 m long x 3 m wide. Floor systems are exposed to furnace heating conditions (refer Figure E6) from the underside and fire-resistant walls are exposed from one side. Asymmetrical walls generally require two tests to evaluate the response to exposure to fire from either side, unless the side exposed to fire can be specified.

Smaller-scale specimens (not less than 1 m x 1 m) can be used to retrospectively determine the resistance to incipient spread of fire performance of a floor or wall system that has previously achieved the required fire resistance level in a fire resistance satisfying the minimum size requirements specified in AS 1530.4.

For universal application of results, the minimum cavity depth should be fire tested.

To determine the RISF, five thermocouple with insulating pads as prescribed in AS 1530.4. shall be fixed to the inner face of the fire-protective covering system. They shall be placed at approximately the centre, and the centre of each quarter section, as shown in Figure E7.

When testing corrugated specimens, the number of thermocouples should be increased to six to provide an equal number of thermocouples at the maximum and minimum specimen thickness.

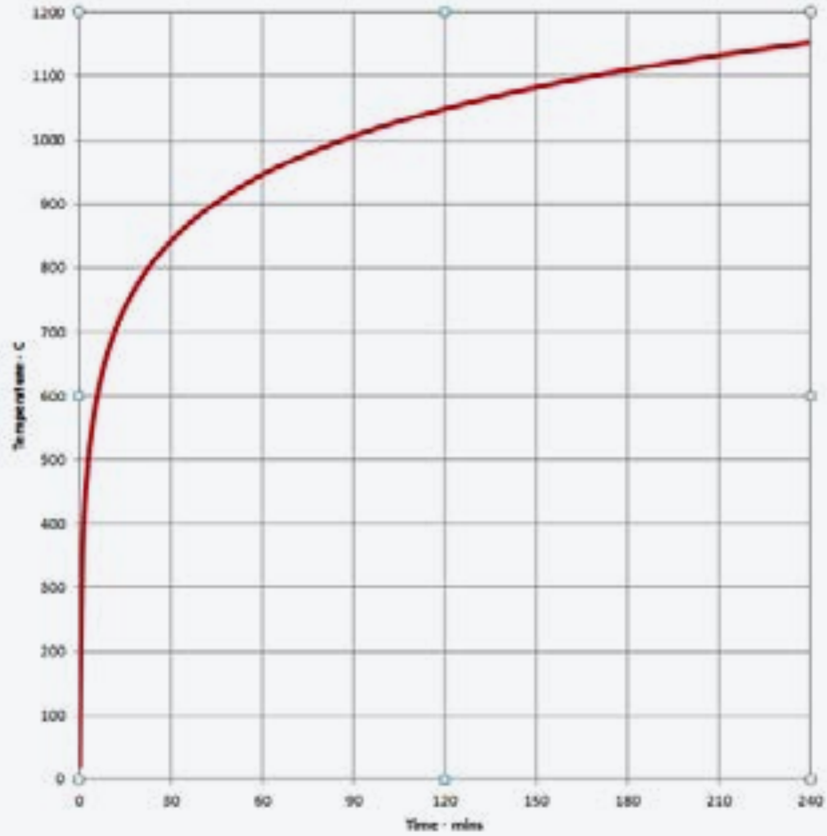


Figure E6: Standard fire resistance test heating regime.

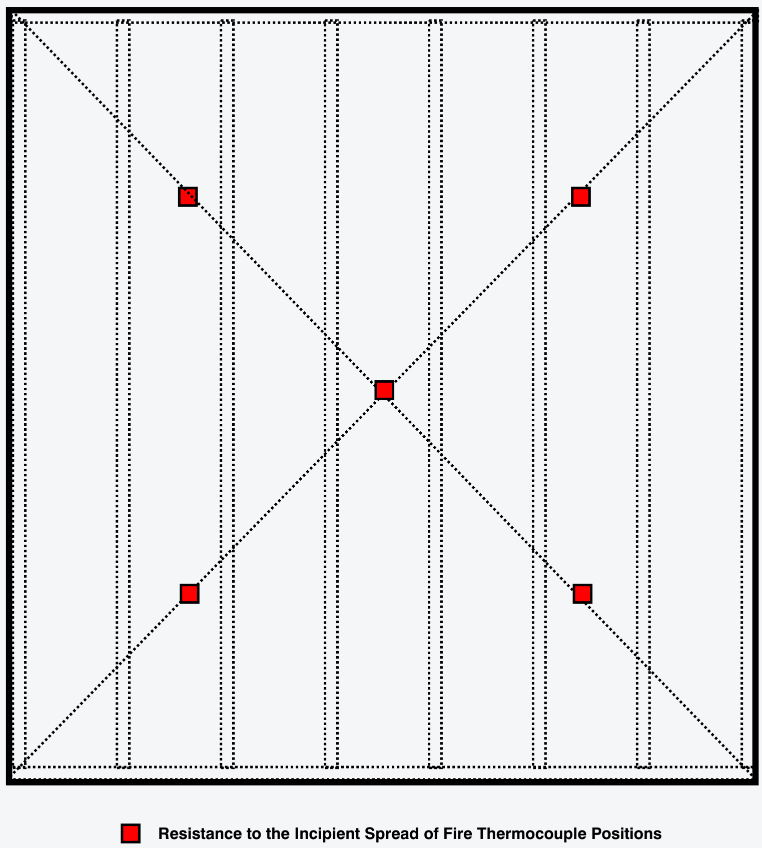


Figure E7: Elevation of a wall showing RISF thermocouple positions.

Sections through typical specimen configurations are shown in Figure E8 to illustrate the correct surfaces to apply thermocouples to determine the RISF. For fire-protected timber, the temperature has to be maintained below the prescribed temperature on the surface of the fire-protective covering facing the void and at the interface with timber elements within the wall or floor. Therefore, if a wall or floor/ceiling system is protected by a board system, for example, the temperatures are measured on the board surface within the cavity even if non-combustible insulation is applied between the timber studs or beams. However, if the non-combustible insulation forms a continuous layer between the timber elements and the board, the thermocouples should be applied to the surface of the insulation, as shown in Figure E8.

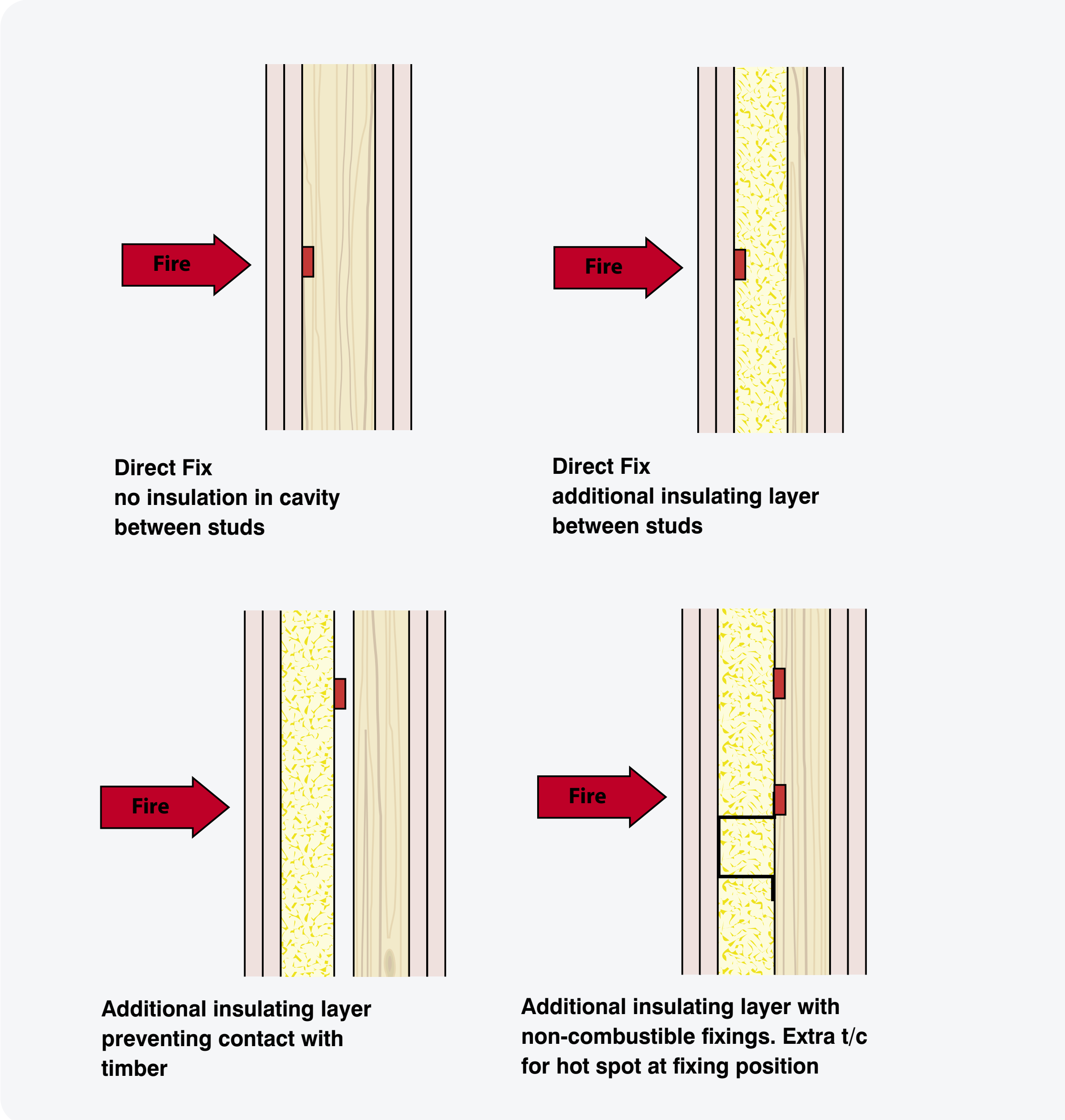


Figure E8: RISF thermocouple positions for typical timber-frame specimen configurations.

Failure in relation to incipient spread of fire is deemed to occur when the maximum temperature of the thermocouples described above exceeds 250°C.

Smaller-scale specimens (1 m x 1 m) can be used to determine the performance of services penetrations in fire-protected timber. Typical examples of thermocouple configurations for various types of service penetrations are shown in Figure E9. Additional thermocouples are shown to allow the simultaneous determination of the FRL of the service penetration system.

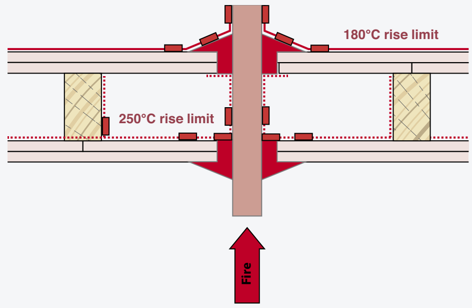
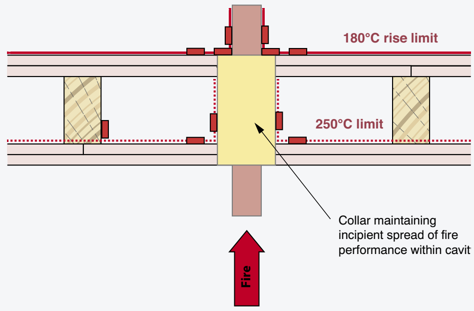
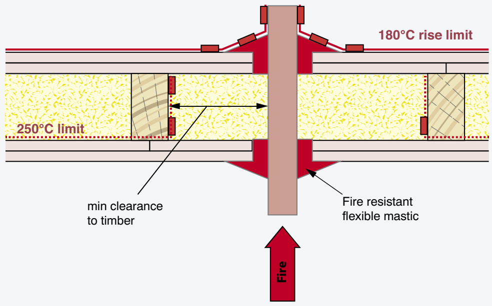
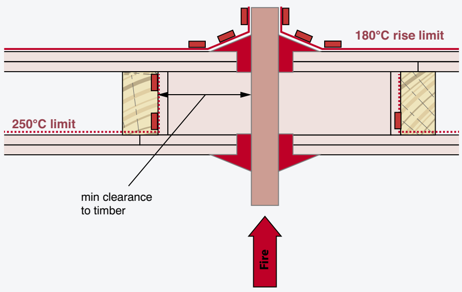
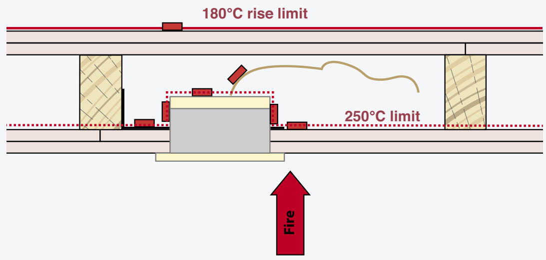
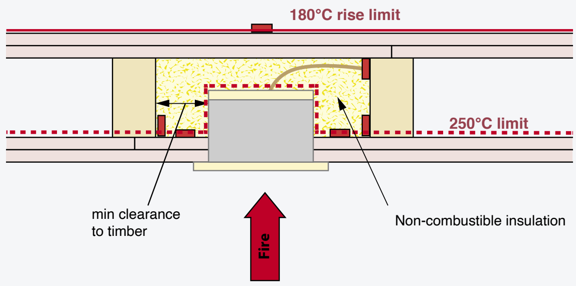
Cable / metal pipe penetration protected with fire resistant mastic.	
Plastic Pipe protected by insulating collar system.	
Cable / metal pipe penetration protected with fire resistant mastic and non-combustible cavity infill. The critical interface for RISF for the service penetration is the surface of the insulation where it is in contact with timber elements. Note: plasterboard surface is the critical surface for determining the RISF of the wall system.	
Cable / metal pipe penetration protected with fire resistant mastic and cavity lined with non-combustible board. The critical interface for RISF for the service penetration is the surface of the lining board where it is in contact with timber elements.	
Proprietary GPO outlet protection system. Note: Thermocouples applied to cable surface connected to the GPO, on fixing bracket and adjacent element.	
GPO outlet with non-combustible cavity infill protection. The critical interface for RISF is the surface of the insulation where it is in contact with timber elements. Note: plasterboard surface is the critical surface for determining the RISF of the wall system.	

Figure E9: Typical thermocouple positions for determining the RISF of service penetrations.

The thermocouples positions must satisfy the following requirements:

- at not less than two points located approximately 25 mm from the edge of the hole made for the passage of the service
- attached to adjacent structural members and those elements that support the penetrating service
- at points on the surface of the penetrating service or its fire stopping encasement, as follows:
  - at least 2 thermocouples located approximately 25 mm from the plane of the general surface of the covering and non-combustible insulation
  - where the seal or protection around the service is tapered or stepped, two additional thermocouples beyond the step or the end of any taper if it is expected that the temperatures will be higher at these points.
- where practicable, at two points on the seal or protection around the service
- one in the centre of the surface of the penetration nominally parallel to the plane of the fire-protective covering if it terminates within the cavity. (e.g. GPO outlets or downlights).

Failure in relation to incipient spread of fire is deemed to occur for the service penetration when the maximum temperature of the thermocouples described above exceeds 250°C.

E3.4 Modified Resistance to Incipient Spread of fire (MRISF) Test Procedures

The MRISF is applicable if all timber elements have a cross-section greater than 75 mm x 75 mm and there are no voids/cavities through which fire and smoke can spread. The MRISF, among other things, relaxes the failure temperature from 250˚C to 300˚C to reflect the reduced risk of fire spread through cavities and higher inherent fire resistance of timber with larger cross-sections. The test procedures are described in Section 3 of Specification A1.1 of the NCC and are summarised below.

Tests must be carried out in accordance with AS 1530.4 or an equivalent or more severe test on the timber element with the proposed non-combustible fire-protective coverings fixed in a representative manner.

Smaller-scale specimens (not less than 1 m x 1 m) can be used to retrospectively determine the MRISF performance of a system that has previously achieved the required fire resistance level in a fire resistance satisfying the minimum size requirements specified in AS 1530.4. If a fire protection system incorporates joints, the test specimens must incorporate representative joints.

To determine the MRISF, interface temperatures must be measured over the following features by a minimum of two thermocouples complying with Appendix C1 and Section 2 of AS 1530.4 as appropriate:

- at joint positions in the protection systems
- at least 200 mm from any joint
- at any other locations where, in the opinion of the Registered Testing Authority, the interface temperature may be higher than the above positions.

Where the fire protective covering is not in contact with the timber, the surface of the fire protective covering is deemed to be the interface.

Figure 75: Typical thermocouple positions for determining the RISF of service penetrations

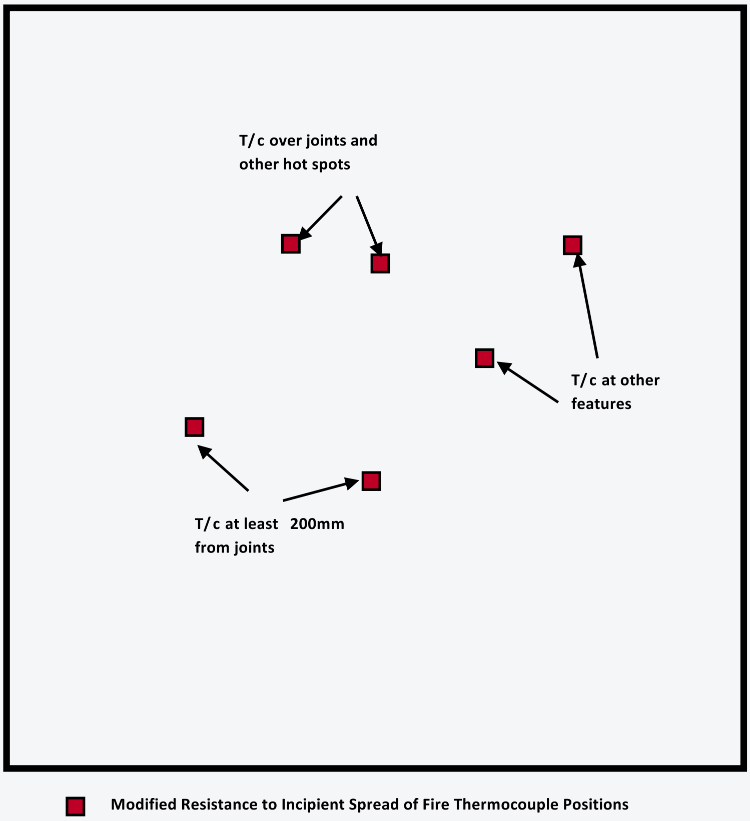


Figure E10: Elevation of a wall showing MRISF thermocouple positions.

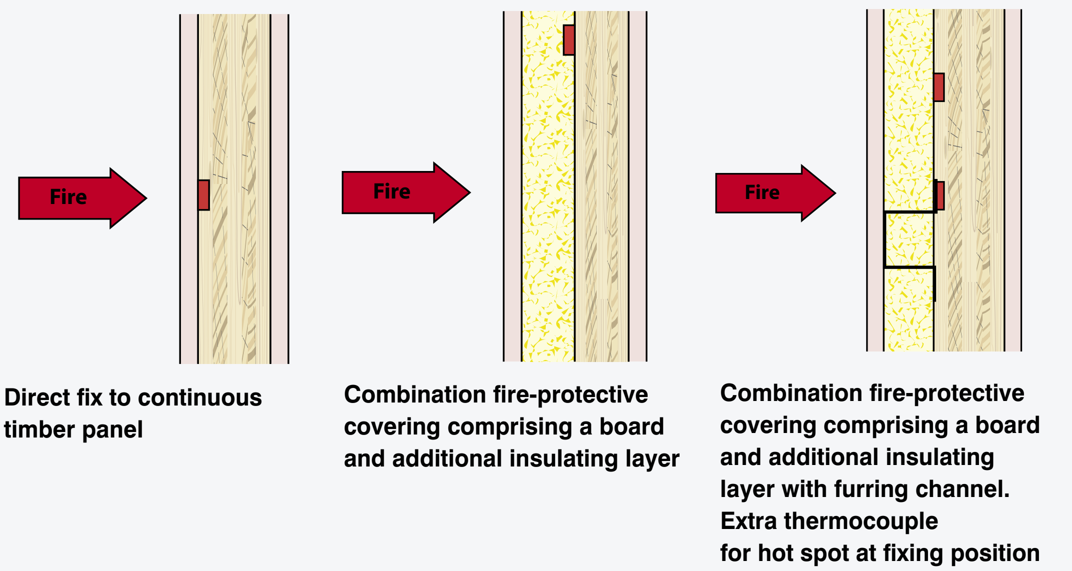


Figure E11: MRISF thermocouple positions for typical panel specimen configurations.

Failure in relation to MRISF is deemed to occur when the maximum temperature of the thermocouples described above exceeds 300°C.

Smaller-scale specimens (1 m x 1 m) can be used to determine the performance of services penetrations in fire-protected timber. Typical examples of thermocouple configurations for various types of service penetrations to determine both the MRISF and FRLs are shown in Figure E12.

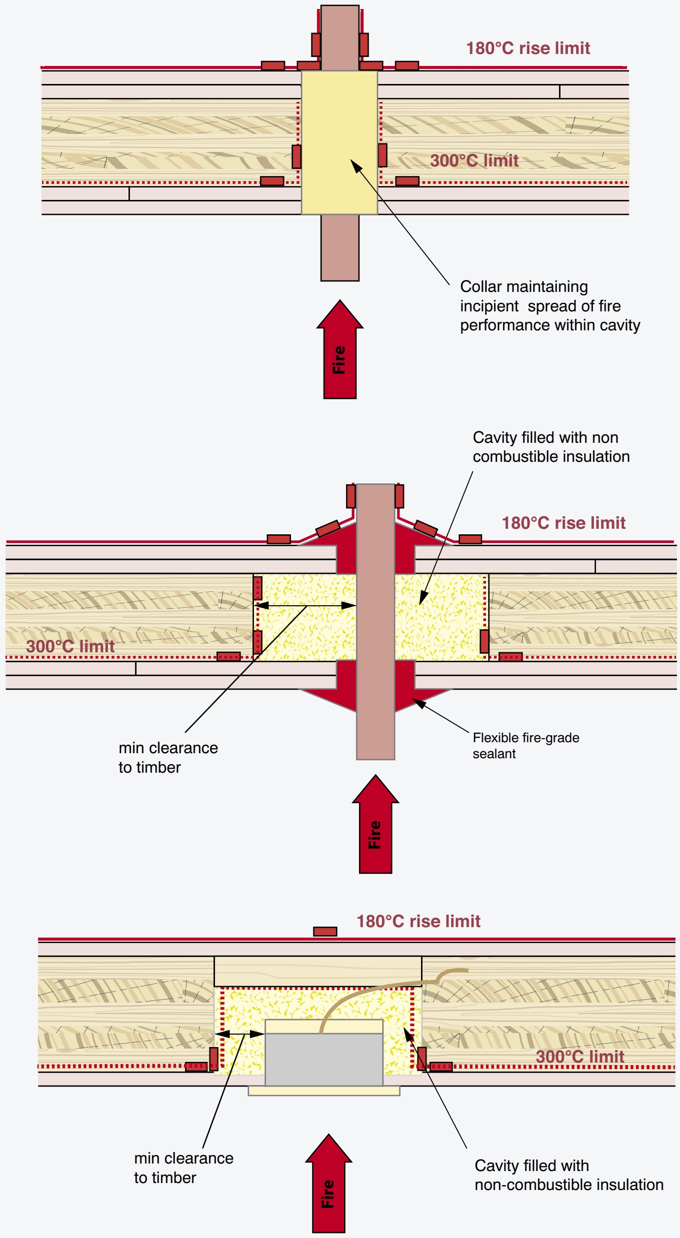


Figure E12: Typical thermocouple positions for determining the MRISF of service penetrations.

Specification C1.13 of the NCC sets out the requirements for cavity barriers in fire-protected timber construction.

Sub-clauses 2(a) to 2(d) set out the required positions of the cavity barriers that are discussed in the body of this Guide. The required performance of cavity barriers is specified in sub-clauses 2(e) to 2(h).

The following compliance options are provided for cavity barriers.

The cavity barrier system must achieve the FRLs specified in Table E3 when mounted in timber elements having the same or a lower density than the timber members in the proposed application or:

- comprise timber of minimum thickness as specified in Table E3; or
- comprise polythene-sleeved mineral wool or non-sleeved mineral wool slabs or strips placed under compression and of minimum thickness as specified in Table E3.

Another option is that, for cavity barriers around doors and windows, steel frames are also Deemed-to-Satisfy the requirements for cavity barriers, provided that wherever possible the steel frames should be tightly fitted to rigid construction and mechanically fixed. It should, however, be noted that if the windows or doors are of fire-resistant construction, the windows or door system needs to be capable of achieving the required fire resistance when mounted in the wall system, notwithstanding the requirements for cavity barriers.

Table E3: Cavity barrier requirements for fire-protected timber.

Cavity Barrier Compliance Options	Maximum FRL required for element cavity barrier is fitted to – min		
	-/60/60	**-/90/90**	**-/120/120**
Cavity Barrier Required FRL – min	-45/45	-/45/45	-/60/60
Timber required minimum thickness	45mm	45mm	55mm
Mineral wool required minimum thickness	45mm	45mm	60mm

The minimum thicknesses of protection are required to be measured in the direction of heat flow. The role of a cavity barrier is normally to prevent a fire spreading from the cavity on one side of the cavity barrier to the other. The head of a double stud partition (Detail A of Figure E13) is a typical example of this, where the direction of heat flow for the cavity barrier would be from the underside to the upper face of the barrier and the thickness dimension is identified as “T” and the width of the seal would be ”W” in the Figure.

The other role for cavity barriers is to reduce the risk of fire spread to cavities occurring around openings for doors and windows within a fire-resistant wall. This configuration is shown as Detail B in Figure E13. For this scenario the heat flow direction is from the occupied area of the building through the framing to the cavity. The thickness dimension is identified as ‘T’ in Figure E13.

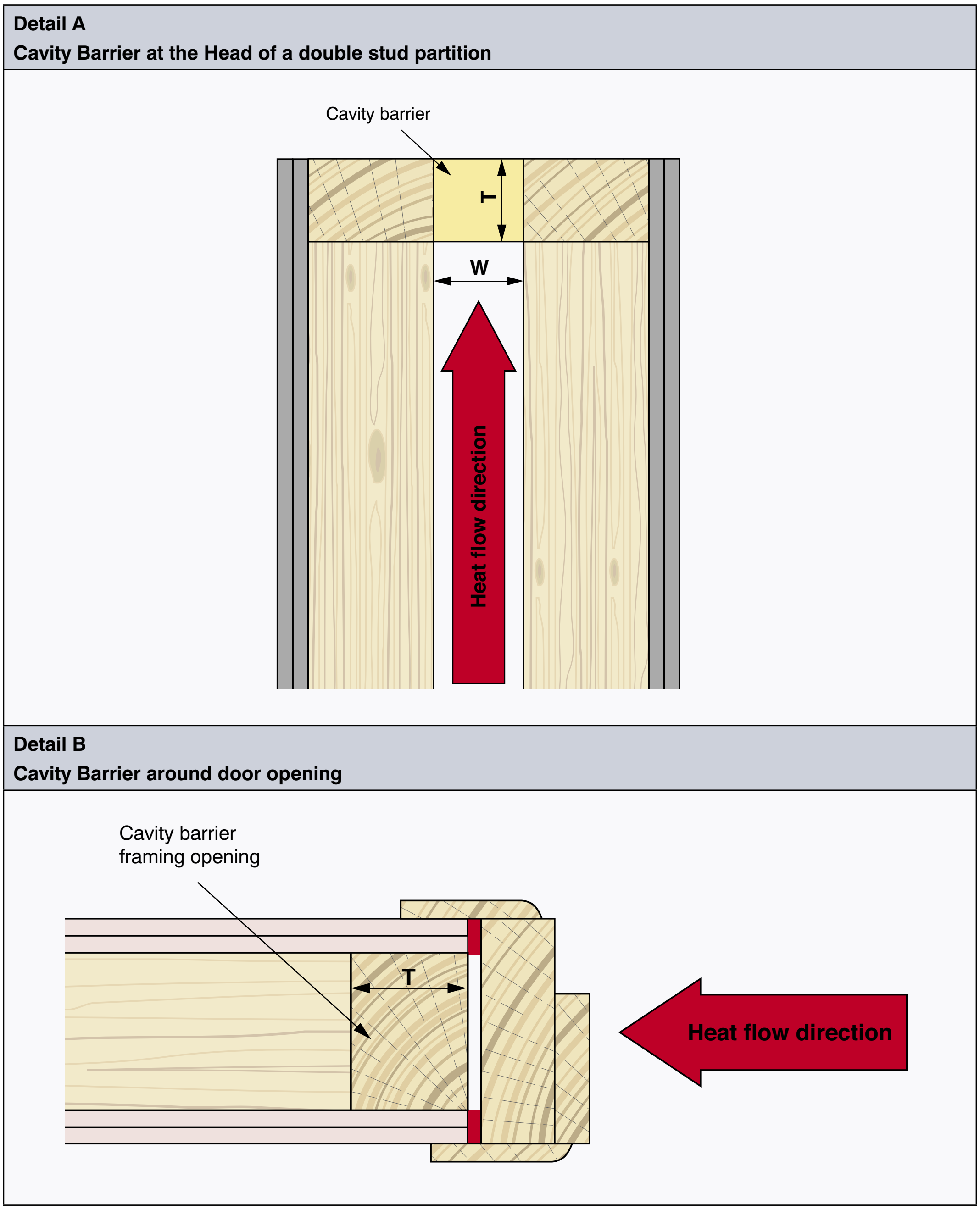


Figure E13: Heat flow direction for cavity barriers.

It is expected that proprietary cavity barrier systems may provide more practical options than the Deemed-to-Satisfy solutions for some applications. To encourage the development and use of these systems, a compliance path has been provided through the specification of FRLs. For smaller-sized cavity barriers, the performance should be determined by testing the cavity barrier as a control joint system in accordance with Section 10 of AS 1530.4:2014 using timber members as the separating element. Specification C1.13 permits the results from such a test to be used for applications where the fire-protected timber is constructed from timber having a nominal density at least equal to the tested timber.

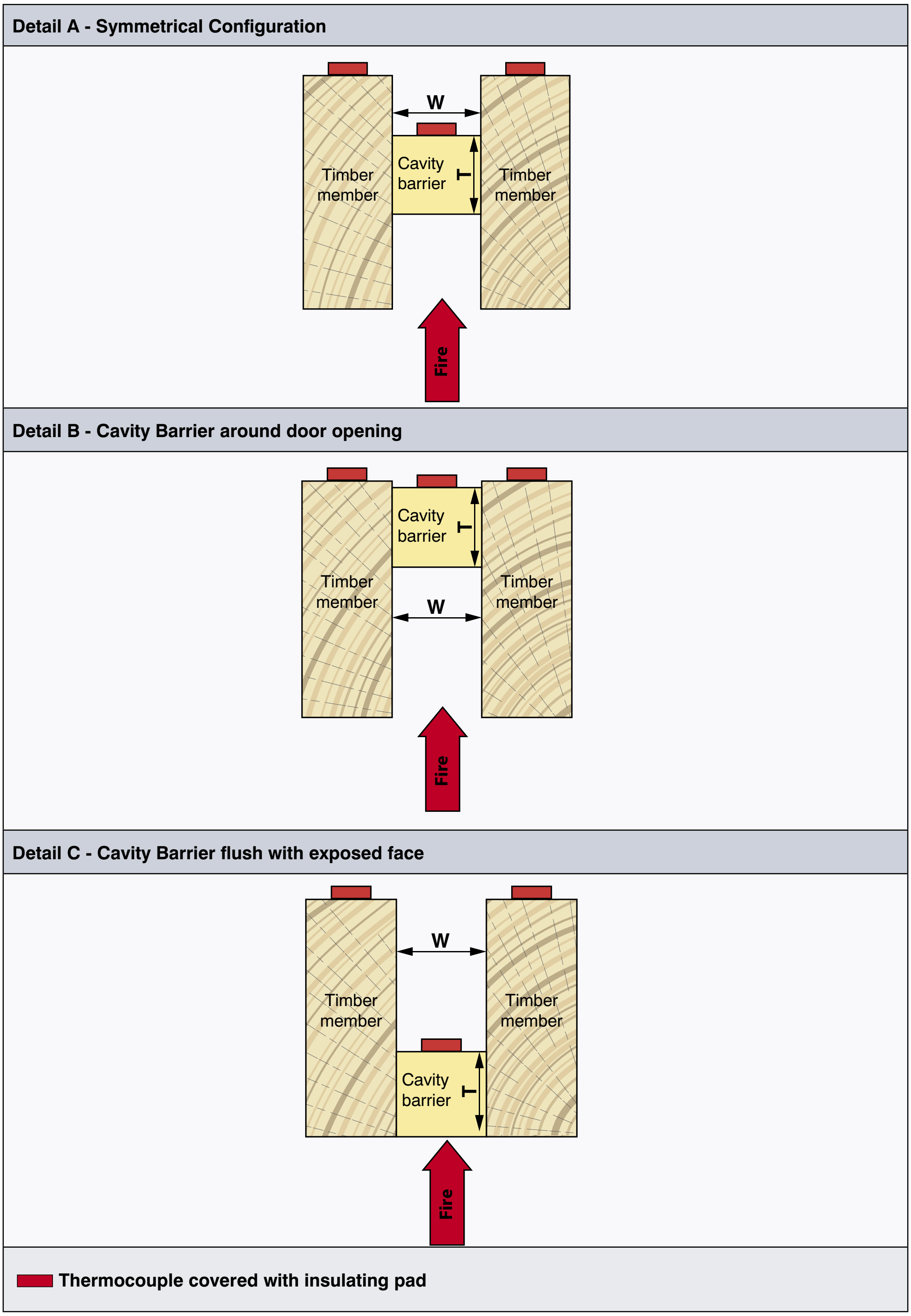


Figure E14: Typical cavity barrier test configurations.

Typical test configurations are shown in Figure E14. The selection of the test configuration(s) depends on how the cavity barrier will be mounted. If the cavity barrier system is symmetrical (e.g. the cavity barrier is to be fitted at the mid-depth of a timber member) then Detail A is appropriate. If the cavity barrier system is not symmetrical both details, B and C should be tested unless the most onerous configuration can be determined by the test laboratory or the cavity barrier use is restricted to one configuration. A report from a registered test laboratory should state the field of application for the cavity barrier based on the test results.

Cavity barriers can be of combustible construction and therefore a timber-framed partition with exposed timber members could be used, subject to the wall achieving the required FRL.

In some instances, it may be more practicable to continue the fire-resistant walls up to roof level in lieu of providing a fire-protected timber roof system with cavity barriers.

Appendix F: Analysis of Fire Data

F1 Fire Loss Estimates

Currently, only limited national fire statistics are published in Australia, and therefore reliance has had to be placed on older data for comparisons. Dowling and Ramsay[45] analysed Australian fire statistics for the period 1989 to 1993. The same data set was also analysed by Thomas and Verghese,[46] who calculated that there were 6.8 fatalities per 1,000 apartment fires.

Since 1993, NSW fire services have published detailed annual statistics until 2006/07. Table F1 and Table F2 have been derived from this data for the period from 2003/4 to 2006/7. [47]

Table F1: Comparison of NSW house and apartment fire fatalities and injuries.

Year	1 and 2 Family Houses					Apartments				
	Fires	Fatalities	Injuries	Fatalities / 1000 fires	Injuries / 1000 fires	Fires	Fatalities	Injuries	Fatalities / 1000 fires	Injuries / 1000 fires
2003/4	2,977	15	430	5.0	144.4	1,285	3	160	2.3	124.5
2004/5	2,879	35	431	12.2	149.7	1,185	11	142	9.3	119.8
2005/6	3,071	13	392	4.2	127.6	1,262	9	181	7.1	143.4
2006/7	2,914	10	448	3.4	153.7	1,242	6	137	4.8	110.3
Total	**11,841**	**73**	**1,701**	**6.2**	**143.7**	**4,974**	**29**	**620**	**5.8**	**124.6**

The results from Table F1 have been consolidated in Table F2 and the average loss per fire added, including an adjustment to 2014 present values.

Table F2: NSW house and apartment fire losses.

Year	1 and 2 Family Houses and Apartments					Av. loss / fire A$	Ave loss / fire A$ at 2014 value
	Fires	Fatalities	Injuries	Fatalities / 1000 fires	Injuries / 1000 fires		
2003/4	4,262	18	590	4.2	138.4	20,859	27,407
2004/5	4,064	46	573	11.3	141.0	28,017	35,920
2005/6	4,333	22	573	5.1	132.2	28,228	34,800
2006/7	4,156	16	585	3.8	140.8	26,784	32,342
Total	**16,815**	**102**	**2321**	**6.1**	**138.0**		**32,617**

The fatalities from house and apartment fires are similar (about 6/1,000 fires) and are comparable to the 6.8 fatalities/1,000 apartment fires estimated by Thomas and Vergese in their analysis of Australian Statistics for the period between 1988 and 1992.

It has not been possible to isolate sprinkler-protected apartment fires in the Australian statistics presented above, but the proportion of sprinkler-protected houses and apartments is currently very low, and therefore the above statistics are considered representative of buildings that are not protected by automatic fire sprinklers.

The average fatality rates between 6 and 6.8 fatalities/1,000 fires from the Australian data are comparable to the 7.3 fatalities /1,000 fires calculated by Hall based on the American data. It is therefore reasonable to expect a similar reduction in fatalities to that calculated from the US data, if an automatic fire sprinkler system is included in an apartment (i.e. a reduction of about 83%).

The average residential fire loss due to fires in NSW was estimated to be A$32,617 per fire at 2014 values, applying adjustments for changes to CPI. These losses can be crudely compared to the US losses by applying adjustments to CPI to estimate 2008 values (the mid-point of the data used in the Hall analysis) yielding a loss per fire of A$28,213 at 2008 values. The exchange rate at mid-2008 was approximately US$0.8 to A$1, which would value the NSW losses at US$22,570 per fire, which is comparable to the US losses of approximately US$20,000/fire. It is therefore reasonable to expect a reduction in direct property damage/home fire of the order of 69%.

F2 General Area of Fire Origin

A breakdown of the areas of fire origin for structural incidents in multi-level apartment buildings attended by the MFB between 1996–2007 was provided in a Post Incident Analysis Report after an apartment fire.[48] Figure F1 is based on this data and includes extracted areas of fire origin that were clearly within individual apartments. Some of those indicated as falling under storage areas, service facilities, means of egress and other areas may have occurred within an apartment. The data also shows a significant occurrence (7%) of fires occurring in the means of egress.

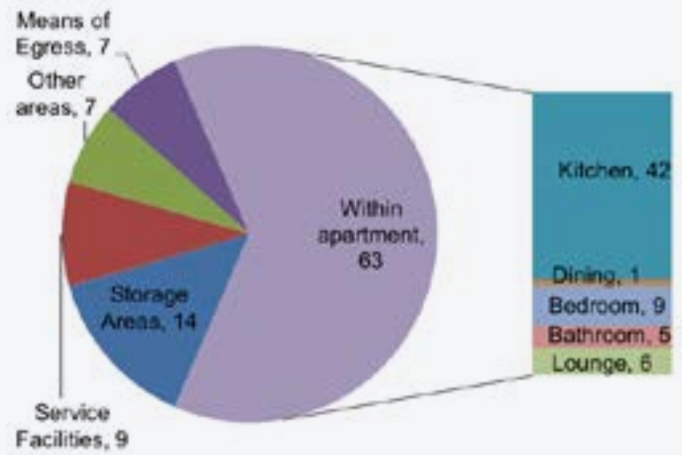


Figure F1: Area of fire origin for multi-level apartment fires attended by the MFB from 1997 to 2007.

A similar analysis has been undertaken for NSW based on published annual statistics for the period from 2003/4 to 2006/7. [47] The results are shown in Figure F2.

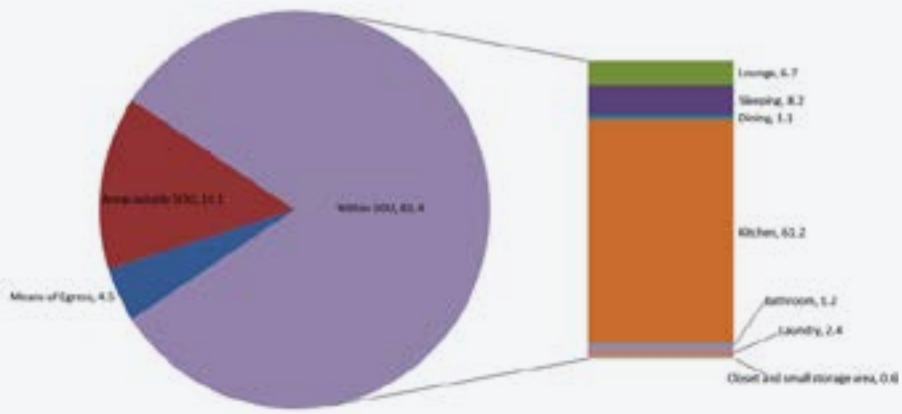


Figure F2: Area of fire origin for multi-level apartment fires attended by NSW Fire Services from 2003 to 2007.

The fires occuring in the means of egress were broken down further based on the frequency of fire starts from the NSW fire statistics and are summarised in Table F3.

Table F3: Fire starts in escape paths and shafts – NSW 2002-3 to 2006-7.

Location	Fire Starts – %
Lobby, entrance way	1.2
Hallway, corridor, mall	1.9
Exterior stairway	0.3
Interior stairway	0.8
Fire-isolated escape route	0.1
Lift, dumbwaiter	0.22
Utility shaft	0.16
Chute	0.02

F3 Fire Starts within Structural Areas

A number of surveys were undertaken, based on council records of the form of construction used for new single dwellings in the Melbourne area for the period 1979–2003. They indicated that, of the form of construction known, more than 90% of single dwellings were of timber-framed construction. It is estimated that a similarly high percentage of timber-framed construction has been adopted for single dwellings in NSW.

Fire statistics including the area of fire origin from single dwellings in NSW and Victoria can therefore provide a reasonable indication of the potential for fire starts to occur within areas of timber-framed construction; although it should be noted that there are no controls applied to internal linings and very few controls applied to external linings of single dwellings and cavity insulation, so the rates of fire starts in these areas are likely to be higher than is expected with the proposed use of fire-protected timber.

Figure F3 provides a breakdown of the area of fire origin in 1 and 2 Family Dwellings in NSW based on published annual statistics for the period from 2003/4 to 2006/7[47].

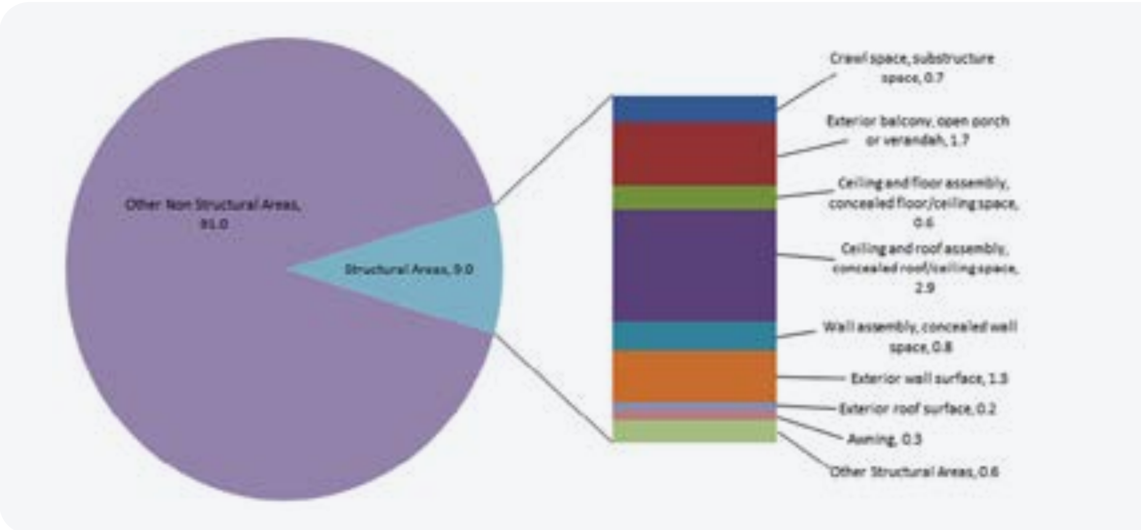


Figure F3: Detailed breakdown of structural areas of fire origin based on NSW fire statistics from 2002/3 to 2006/7.

A large number of the structural areas listed in Figure F3 relate to external areas and surfaces that are not applicable to the fire-protected timber. Since the primary focus of this analysis is concrete/masonry and non-combustible walls, the most relevant statistic is that about 0.8% of fire starts occur within a wall assembly.

Ignitions in timber-framed floors and roof constructions will also be considered in the analysis. The statistics indicate approximately 2.9% of fires occur in the concealed space between a roof and ceiling and 0.6% of fires occur in the concealed space between a floor and ceiling. The large difference in fire starts between floors and roof construction may in part be due to a fewer number of two-storey (or more) single dwellings.

G

Appendix G: Multi-scenario Quantitative Risk Assessment Supplementary Data

G1 Contribution of Timber Elements to Fire Load

G1.1 Overview

The NCC 2016 requirements for mid-rise timber buildings include additional supplementary controls to reduce the probability of a contribution from the timber. They apply the incipient spread of fire criteria from AS 1530.4 of 250°C on the inner surface of protective coverings for a period of 45 minutes for timber-framed construction, and an interface temperature of 300°C for massive timber panels with no cavities for 30 minutes. These criteria are in addition to the FRL levels of 90/90/90 for loadbearing elements and -/60/60 for non-loadbearing elements, which are also required to be met.

The potential for protected timber construction to contribute to the effective fire load and hence increase the severity was raised when an extension of the Class 2 Concession to include a Class 3 Concession for low-rise buildings was sought and addressed by means of a full-scale fire experiment, which demonstrated that there was no increase in the fire severity of an enclosure under typical natural fire conditions.[5(pp18-35)]

The Monte Carlo analysis for mid-rise buildings includes consideration of the potential consequences of incorrect installations with gross defects and other extreme circumstances, and therefore the probability and consequences of a significant increase in the fire severity from protected timber-frame members under these adverse conditions was considered.

Currently, the NCC does not directly control the fire load within individual apartments of a Class 2 building, and non-combustible elements of construction can be clad with decorative combustible materials (including timber) of any thickness. However, a conservative approach to address issues raised by stakeholders was adopted and a more detailed analysis is provided below of the potential contribution to the fire load.

With modern furnishings containing larger proportions of plastics and the increased amount of lightweight furniture, typical residential fires tend to be relatively fast growing and produce large volumes of volatiles post-flashover, leading to conditions that are heavily ventilation-controlled with long flame extensions from windows as the unburnt volatiles mix with air outside the building. During this stage of the fire, as the tests performed for the low-rise concession demonstrated[5(pp18-35)], there will be no contribution from fire-protected timber. Also, while the fire remains under ventilation-controlled conditions, any additional volatiles would not be consumed within the enclosure of fire origin and enclosure temperatures may tend to be lower, due to oxygen constraints.

Therefore, if volatiles are released, any contribution to the fire load would tend to extend the duration of a fire after it has progressed towards a fuel-controlled burning regime. During the low-rise concession tests, the fire progressed to a fuel-controlled regime and there was no evidence of an increase in severity of the fire from the protected timber frame, despite some minor charring and temperatures of the timber peaking above 350°C.

While a review of literature (e.g. Babrauskas)[49] shows that timber starts to degrade below 250°C, the rate of degradation is relatively slow and hence production of volatiles will be low. Similarly, timber can ignite at temperatures lower than 300°C, but the probability of ignition is strongly time dependent and is also dependent upon oxygen content, moisture content, the size of the specimen and other factors, and ignition temperatures can be above 400°C.

Recently published results based on cone calorimeter tests on timber samples protected by fire-protective coverings subjecting specimens to radiant heat fluxes of 50kW/m^2 and 75kW/m^2 (yielding similar timber heating rates to fully developed fires and the standard fire resistance test heating regime) have been published (Su and Lougheed[39]). This research found that the plywood substrates ignited at an average interface temperature between 320 and 350°C, indicating that both the adopted limits for general timber construction (250°C) and massive timber construction (300°C) in the NCC 2016 and used in the supporting analysis were conservative.

G1.2 Timber-framed Construction

Figure G1 shows the fire-exposed face of a test specimen about three minutes after the test in free air, prior to application of water. The specimen had been subjected to a 90-minute fire resistance test. The figure shows the openings left after a 100 mm unprotected PVC pipe penetration in the lower part of the specimen and an unprotected electrical light switch had been consumed during the test, allowing the fire to penetrate the cavity, and representing an element with severe installation faults. At this stage, the specimen was in an open laboratory area with no ventilation restrictions and – despite the fire burning within the cavity – the plasterboard facings remained intact, with flames only projecting from small openings and from the interface of the partition edge and furnace seal.

Figure G1: Exposed face of timber-framed plasterboard specimen about three mins after completion of a 90-minute fire resistance test in a free air environment.

On the basis of the above discussion and with the controls proposed above, it is likely that there will be no appreciable contribution from protected timber-frame members prior to substantial fall off of the facings – substantial fall off is likely to occur at the equivalent fire-resistant period of 12 minutes before the nominal fire resistance is achieved by the protected timber member, if there is no intervention based on the inherent fire resistance of lightweight timber-framed construction. The number of scenarios where this occurs will be very low.

A conservative approach has been adopted by assuming a significant contribution to the fire severity will occur after exposure to the equivalent of 45 minutes of the standard fire test based on the definition of fire-protected timber.

An initial Monte Carlo run was undertaken to determine the proportion of scenarios where the fire is suppressed or burns out prior to failure of a timber-framed element.

Typical results for a mean fire load of 500MJ/m2 on the 7th (top) floor are shown in Figure G2. In this example, burnout would occur before a duration equivalent to 45 minutes fire resistance in 45% of scenarios. The fire would be likely to be suppressed before achieving the equivalent of 45 minutes fire resistance in 54% of scenarios, leaving about 1% where the timber substrate is deemed to ignite.

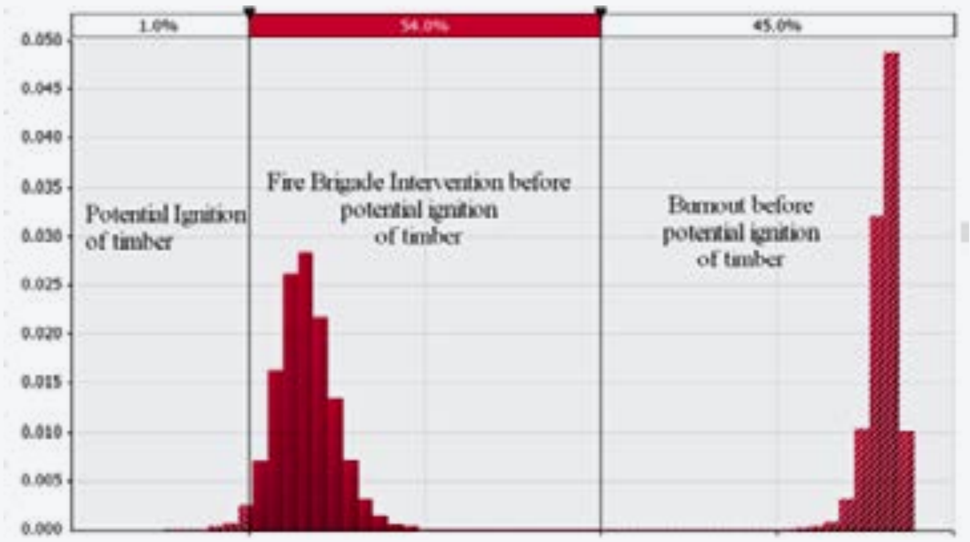


Figure G2: Typical performance of fire-protected timber coverings for timber-frame construction – mean fire load of 500 MJ/m² on the 7th floor.

The fire load was therefore increased for 1% of scenarios.

To establish an upper bound for the contribution of the potential energy that could be released from typical timber-framed elements, it was assumed all timber undergoes efficient combustion within the enclosure.

A typical wall was assumed to be 6 m x 2.4 m high and comprise 90 x 45 mm studs at 450 mm centres, with top and bottom plates and central noggings of the same dimension and of party wall design (two frames).

No of studs	(6/0.45) + 1	say 16
Length of timber	((16 x 2.4) + (3 x 6)) x 2	113 m
Mass of timber =	113 x 0.09 x 0.045 x 450	206 kg
Increased fire load / m² based on 6x4m room	206 x 18/24	155MJ/m²

A typical floor was assumed to comprise 300x50mm joists at 450 mm nominal centres spanning 4 m.

No of joists		say 16
Length of joists	16 x 4	64 m
Ring beam		40 m
Floorboards ignored assumed covered by insulation		
Mass of timber =	104 x 0.3 x 0.05 x 450	702 kg
Increased fire load / m² based on 6 x 4 m room	702 x 18/24	527MJ/m²

These increases will be expected to overestimate the contributions substantially, based on the discussion in the previous section. To simplify modelling, the fire load was increased by 500MJ/m² for the proportion of cases that the timber temperatures were estimated to exceed 250°C, which would be expected to yield conservative results.

McGregor[37] undertook a series of fire tests to investigate the contribution of CLT panels to room fires. Two tests were performed using propane gas burners on protected and unprotected CLT but, due to variations in the test procedures between the tests and pre-heating as a result of restarting the first fire test, these are not discussed further. The remaining three tests were performed with representative fire loads for bedrooms. Temperature data was lost from one of these tests but the configuration was retested. Therefore, this analysis of the results has focused on Tests 4 and 5. These were performed in an enclosure constructed of CLT panels with internal dimensions 3.5 m x 4.5 x 2.5 m high with an opening 2 m high x 1.07 m wide. Furnishings/contents representing bedroom fire loads of 553MJ/m^2 and 529MJ/m^2 for Tests 4 and 5, respectively, were provided.

The CLT panels were exposed in Test 5 and protected with two layers of 13 mm fire-grade plasterboard in Test 4. Figure G3 shows the approximate average enclosure temperatures from Tests 4 and 5, with a parametric curve derived in accordance with the procedures described in this Appendix with an assumed load of 529 MJ/m^2 and the calculated temperatures of a target steel element to compare the severity of exposures.

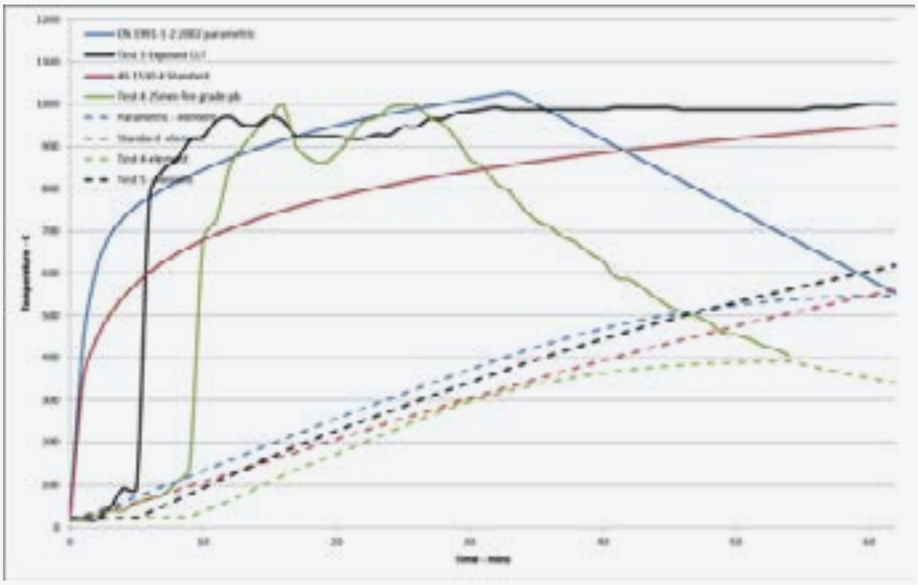


Figure G3: Average enclosure temperatures for McGregor Tests 4 and 5 compared to a parametric fire curve with a fire load of 529MJ/m^2.

In Test 4, there was no contribution from the CLT, with the plasterboard providing full protection. From examination of the average enclosure temperatures, it can be observed that until the fire load excluding the CLT had been substantially consumed the enclosure temperatures were similar, if the pre-flashover phase is excluded. For the protected enclosure, the fire burnt out and decayed; whereas, in Test 5 the CLT continued to burn, extending the duration of the fully developed fire beyond 62 minutes at which stage the test was terminated. Using the target element temperatures, the equivalent fire resistance periods were estimated from the enclosure temperatures and compared to the parametric curve. The results of this comparison are shown in Table G1. The fire severity for Test 4 was estimated to be equivalent to a 40-minute fire-resistant test.

Table G1: Equivalent fire resistance exposure periods for Tests 4 and 5 compared to parametric curves.

Scenario	Equivalent fire resistance	Comments
Test 4 Protected CLT	40 min	Burnout
Test 5 Unprotected CLT	71 min	Suppressed after 62 minutes
Parametric Curve 529MJ/m^2	59 min	Full fire load from Test 4
Parametric Curve 365MJ/m^2	43 min	Consumed fire load (69% of actual fire load) based on oxygen consumption calorimetry
Parametric Curve 977MJ/m^2	98 min	Based on McGregor-measured energy released for Test 5
Parametric Curve 1077MJ/m^2	115 min	Based on estimated timber consumed in Test 5
Parametric Curve 954MJ/m^2	96 min	Test 5 estimated exposure based on proposed methods
Parametric Curve 1616MJ/m^2	165 min	Simulating full burnout of CLT using proposed calculation method
Test 5 Extrapolated at 1,000°C for 105 min	119 min	Simulating full burnout of CLT at constant temperature

Oxygen consumption calorimetry was undertaken during the tests, from which it was estimated that the heat released during Test 4 was equivalent to 365 MJ/m2 (0.69 of the total fire load). Figure G4 shows the revised parametric curve based on a fire load of 365 MJ/m2 compared to Test 4 and 5 average temperatures, with the time scale offset to remove the pre-flashover growth phase. For Test 4 there is a reasonable correlation with the parametric curve, providing an equivalent fire resistance exposure of 43 minutes compared to 40 minutes for Test 4. This indicates that applying the parametric curves with high fire loads will tend to over-predict the fire severity, especially if no allowance for combustion efficiency is made.

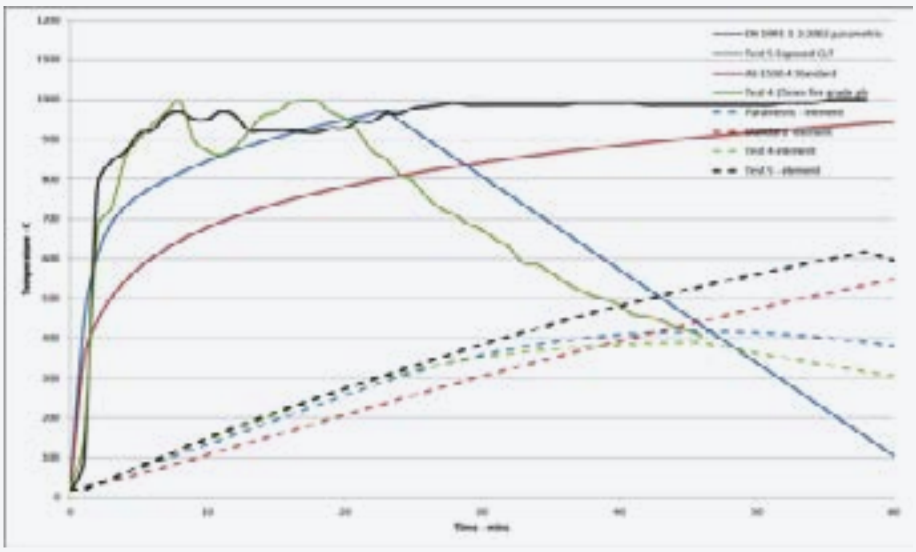


Figure G4: Average enclosure temperatures for McGregor Tests 4 and 5 compared to a parametric fire curve with fire load reduced to 365 MJ/m^2 and axis offset to remove pre-flashover growth.

Oxygen consumption calorimetry was also used to estimate the total heat released in Test 5, allowing the additional contribution from the CLT to be estimated. McGregor found the additional contribution to be 612 MJ/m^2 during Test 5. From Figure G4, it can be observed that the average temperatures were similar between Tests 4 and 5 for the first 20 minutes of a fully developed fire, indicating that the additional combustion must have occurred outside the enclosure. This is consistent with the fire being ventilation-controlled but, as the moveable fire load (furnishings/contents) was consumed, an increasing proportion of the volatiles produced from the CLT will burn within the enclosure. The enclosure temperature was between 900 and 1,000°C from about 5 minutes (ignoring pre-flashover stage) for a period of just less than 60 minutes, at which point Test 5 was stopped. Char depths were measured after the tests, with most of the CLT panels exhibiting char depths between 50 and 70 mm. An average char depth at the time that Test 5 was stopped of approximately 60 mm has been assumed for the following indicative calculation of the total energy available if the consumed timber undergoes complete combustion.

Internal surface of CLT = (3.5+4.5) x 2.5 x 2 + (3.5 x 4.5) – (2 x 1.07) = 53.61 m^2

Volume of CLT consumed at end of Test 5 = 53.61 x 0.06 = 3.22 m^3

Mass of timber = 3.22 x 480 = 1546 kg

Equivalent to 1546 x 18 = 27,828MJ (assuming heat of combustion 18MJ/kg)

or (27828/3.5 x 4.5) = 1766MJ/m^2

This is much higher than the additional heat release rate due to combustion of the CLT of 612MJ/m^2 calculated by McGregor. McGregor's heat release estimates were based on oxygen consumption calorimetry; collecting the gases released from the enclosure and therefore the value also includes combustion taking place outside the enclosure. Therefore, the difference in heat release must be accounted for by inefficient combustion including loss of unburnt volatiles or volatiles that have undergone partial combustion and unburnt solid residues within the enclosure, among other things. Hakkarainen[36] also investigated explanations for temperature reductions in enclosures when CLT was exposed.

The heating regimes in both tests can be idealised to steady state conditions with the enclosure at about 1,000°C followed by decay. For Test 4 (protected CLT) the steady state conditions were maintained for about 20 minutes before the fire decayed as the moveable fire load was consumed. For Test 5 (exposed CLT) the steady state conditions were maintained for 60 minutes, at which stage the test was stopped. If it is assumed that the production rate of volatiles for the CLT is constant while the enclosure is at a constant temperature, then the equivalent of 1766MJ/m^2 of fuel would be consumed over a 60-minute period at a rate of:

1766/60 = 29.43MJ/m^2/min

During the first 20 minutes of steady state burning, the moveable fire load provides sufficient energy to heat the enclosure with some volatiles burning outside the enclosure. Due to the large volumes of volatiles burning, combustion would be inefficient and the volatiles from the CLT may not undergo combustion inside or outside the enclosure but may be released as smoke (unburnt gases). This assumption is consistent with heat flux measurements taken by Hakkarainen outside test enclosures, which indicated similar peak values irrespective of whether or not the CLT was protected.

Therefore, the total heat released from the CLT assuming efficient combustion for a 40-minute period would be:

29.43 x 40 = 1,177 MJ/m^2

It is reasonable to assume a similar burning efficiency to that derived for the moveable fire load (69%) which yields an estimate of the heat released from the CLT during test 5 of:

1,177 x 0.69 = 812 MJ/m^2

This crude estimate provides an overestimate of approximately 32% compared to the measured value of 612 MJ/m^2, but has ignored the heat contribution from the fire load during the decay stage, which would further reduce this variance.

Parametric curves were generated with fire loads of 1,177 MJ/m^2 (365 +812) and 977 (365+612) and compared with the 60-minute tests. Both parametric curves overestimate the maximum enclosure temperature but the duration of the fire for the fire load of 1,177 MJ/m^2 significantly exceeds 60 minutes. From Table G1, it can be seen that the equivalent fire resistance exposure for Test 5 was 71 minutes, with the parametric curves for fire loads of 977 and 1,177 MJ/m^2 predicting equivalent fire resistance periods of 98 and 115 minutes, respectively.

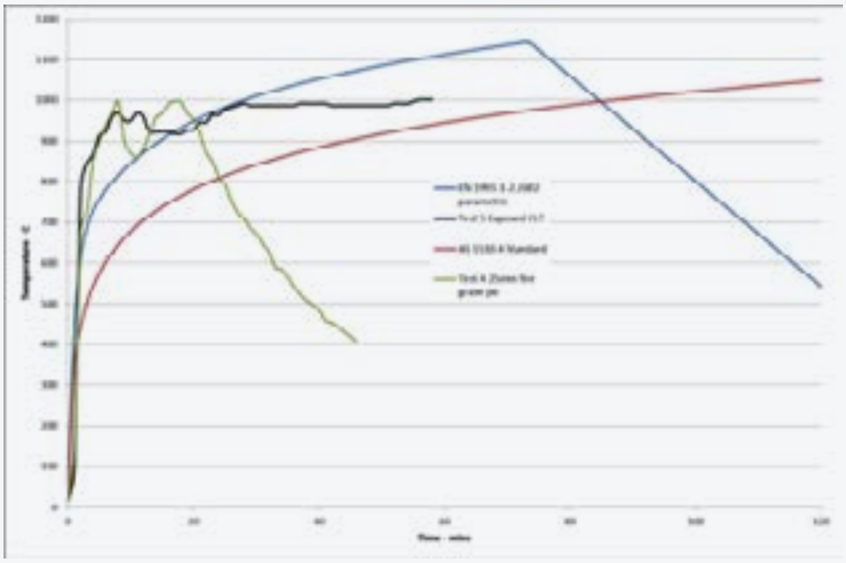


Figure G5: McGregor tests – Parametric curve with assumed fire load of 1,177 MJ/m².

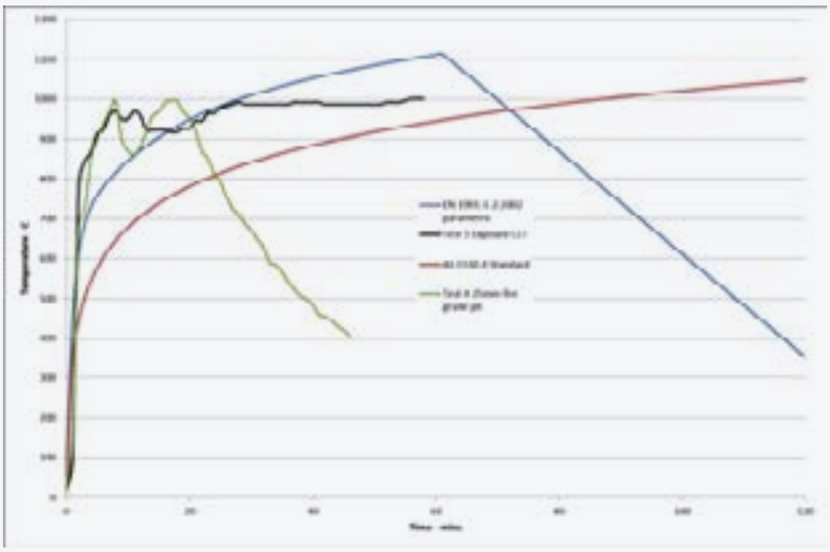


Figure G6: McGregor tests – Parametric curve with assumed fire load of 977 MJ/m².

Since the lower value still provides an overestimate of 28 minutes, it is considered appropriate to apply a burning efficiency of 50% to the CLT fire load, which would yield a contribution of 589 MJ/m² when simulating Test 5.

The fire was suppressed at the end of Test 5 before all the CLT had been consumed.

Figure G7 shows the predicted temperatures compared to actual temperature for Test 5 with a fire load of 589 MJ/m² from the CLT and 365 MJ/m² from the moveable fire load assumed (total 954 MJ/m²). The parametric curve predicts equivalent exposure for Test 5 with a fire load of 954 MJ/m² of 96 mins compared to the estimate based on the average enclosure temperature of 71 mins.

The equivalent fire resistance exposure for a parametric curve with an assumed fire load of 1,616 MJ/m² was estimated to be 165 mins. The equivalent fire resistance exposure based on Test 5 but with the enclosure temperatures extrapolated to 105 mins with assumed enclosure temperature of 100°C was estimated to be 119 mins. While this demonstrates the conservatism of the parametric curves, the use was considered reasonable having regard for the uncertainties of the inputs.

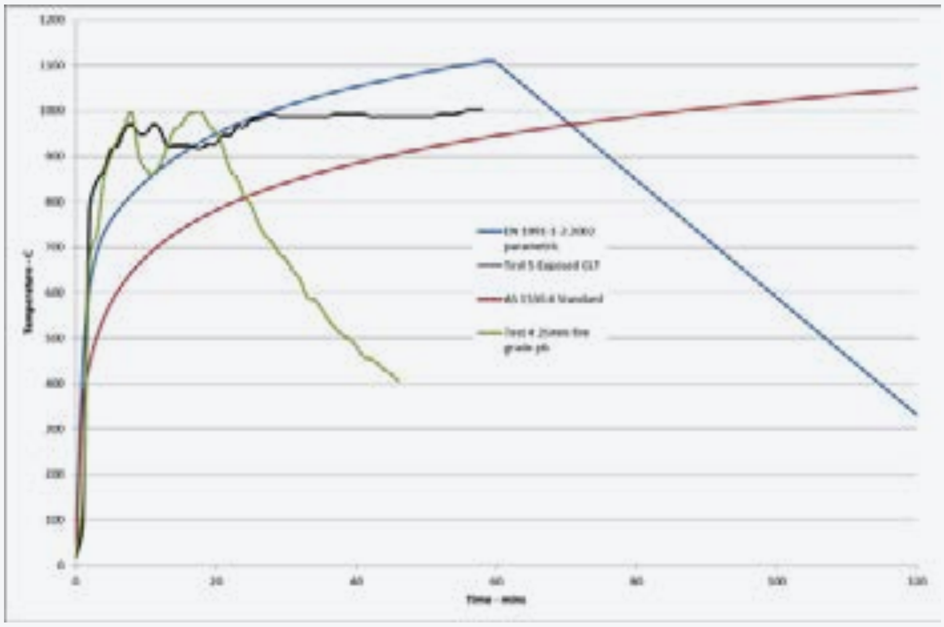


Figure G7: McGregor tests – Parametric curve with assumed fire load of 954 MJ/m².

Massive timber elements are required to be protected to reduce the probability of the element contributing to the fire severity of an enclosure fire. The minimum modified resistance to incipient spread of fire (MRISF) for most applications will be the equivalent of 30 minutes fire resistance in accordance with the NCC 2016 requirements.

The protected loadbearing elements are generally required by the NCC 2016 to achieve a fire resistance level of 90 minutes for loadbearing elements and 60 minutes for non- loadbearing elements in Class 2 band 3 buildings.

A typical CLT panel for these applications was assumed to be 150 mm thick.

Based on the above discussion, the following approach was adopted to model the performance of massive timber elements:

i. The coverings required for fire-protected timber will prevent the timber contributing to the fire severity for the equivalent fire resistance period of 30 minutes within an SOU based on the NCC 2016 requirements.

ii. Monte Carlo fire scenarios were run using parametric curves and if full burnout of the fire, automatic fire sprinkler suppression or fire brigade intervention do not occur before the elements are exposed to the equivalent fire resistance periods listed in (i) it will be assumed that the massive timber member will make a contribution to the fire load.

iii. It is assumed that no contribution is made until the interface temperature exceeds 300^{o}C.

iv. A preliminary Monte Carlo run was undertaken to establish the proportion of fire scenarios that the massive timber may become involved in.

v. The additional fire load was based on a typical 4.5 m x 3.5 m x 2.5 m enclosure using the methods derived above as follows:

Internal surface of CLT = (3.5 + 4.5) x 2.5 x 2 + (3.5 x 4.5) – (2 x 1.07) = 53.61 m^2

Volume of CLT consumed (150 mm element) = 53.61 x 0.15 = 8.04 m^3

Mass of timber = 8.04 x 480 = 3,859 kg

Equivalent to 3,859 x 18 x 0.5 = 3,4733 MJ (assuming heat of combustion 18 MJ/kg and 50% combustion efficiency)

or 27828/3.5 x 4.5) = 2,205 MJ/m^2.

In addition, the moveable fire load will provide the fire load to overcome the coverings to the plasterboard (say 295 MJ/m^2). The remainder of the moveable fire load will be assumed to be lost as excess volatiles, since the fire is ventilation-controlled.

Therefore, if the CLT panels become involved in a fire the total potential fire load was assumed to be about 2,500 MJ/m^2.

To demonstrate the approach, an initial Monte Carlo run was undertaken to determine the proportion of scenarios where the fire is suppressed or burns out prior to failure of a fire-protected massive timber element. The results for a mean fire load of 500MJ/m^2 on the 7th (top) floor are shown in Figure G8. In this example, burnout would occur before a duration equivalent to 30 minutes fire resistance in 2.6% of scenarios; the fire would be likely to be suppressed by the fire brigade before achieving the equivalent of 30 minutes fire resistance in 63.4% of scenarios; leaving about 34% where the timber substrate is deemed to ignite. The fire load will therefore be increased for this proportion of scenarios to a fixed value of 2,500 MJ/m^2.

Similarly, the proportion of fires where timber is deemed to ignite and contributes can be calculated for scenarios on different floors and with different fire loads.

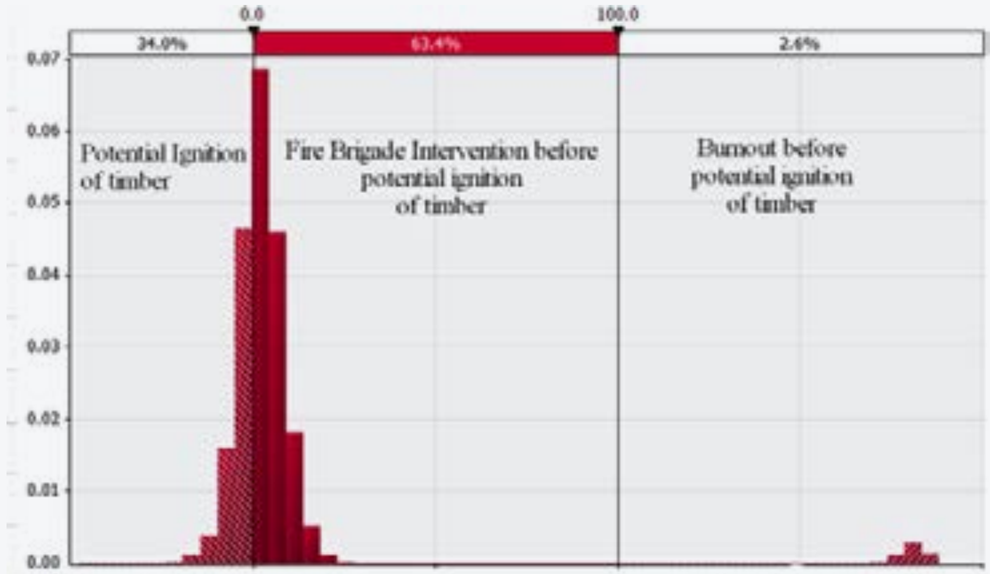


Figure G8: Typical performance of fire-protected timber coverings for massive timber construction – mean fire load of 500 MJ/m^2 on the 7th floor.

G2 Derivation of FRL Distributions

G2.1 Two Peak FRL Characterisation

Effectiveness can be considered to be a combination of efficacy and reliability. It is practical to express efficacy in terms of the time to failure when exposed to a standard heating regime such as AS 1530.4, ISO 834[50] or ASTM E119[51], because these methods are used for regulatory purposes and there is a very large volume of existing test data. Reliability can be considered in terms of the probability of the design performance level being achieved.

There are many factors that can affect the efficacy of passive fire protection systems. Examples are given in Table G2.

There will also be variations in the properties of materials used for structural elements and the applied loads during a fire event that can also be accounted for in the distribution.

Table G2: Factors affecting efficacy of passive systems.

Ref	Factors	Potential Impact	Est. Frequency
1	Gross defect (e.g. substitution of fire-protective coverings with standard lining materials or gross fixing errors)	Minimal protection provided by applied protection – fire resistance approximates to the inherent fire resistance of underlying structure plus a minor contribution from the lining or in concrete structures substantial spalling occurs	Relatively rare and unlikely to be systemic throughout a structure if adequate controls are in place
2	Normal variations in materials and installation practices	Typically manifests as a normal distribution of performance around the mean fire resistance	Will occur with all systems
3	Minor variations in method of fixing	Board systems tolerant of minor variations in fixing systems. Other systems such as masonry walls can be prone to premature failure due to construction errors[52]	Minor variations would occur frequently but impact on performance relatively low
4	Sensitivity to heating regimes	Fire-protective boards are normally resilient to variations in the heating rate but other systems such as glazing & intumescent coatings may be more sensitive	Low frequency of major degradation in performance would be expected
5	Aging	There is a risk of materials deteriorating with age. For board materials this impact is considered low	Low frequency
6	Unprotected large service penetrations	Could allow fire to spread through hole formed in barrier or fire spread to structural members by-passing fire-protective coverings	

A common approach is to define a normal distribution to characterise the potential variation in FRLs due to the above factors; however, some factors such as gross defects can cause very large reductions in performance. The two peak FRL characterisation proposed by England[7] was therefore adopted. Essentially, the FRL is characterised by combining two normal distributions, one with a mean value equal to the notional FRL and the other equal to a mean FRL based on the expected performance of the element with a gross defect.

This is best demonstrated by an example.

Consider an enclosure with eight loadbearing elements – six loadbearing wall elements and two loadbearing floor elements – as shown in Figure G9.

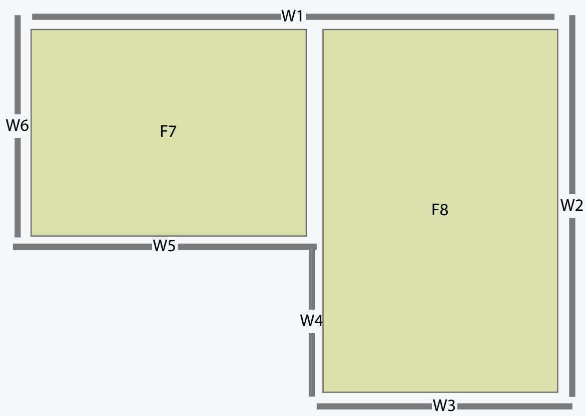
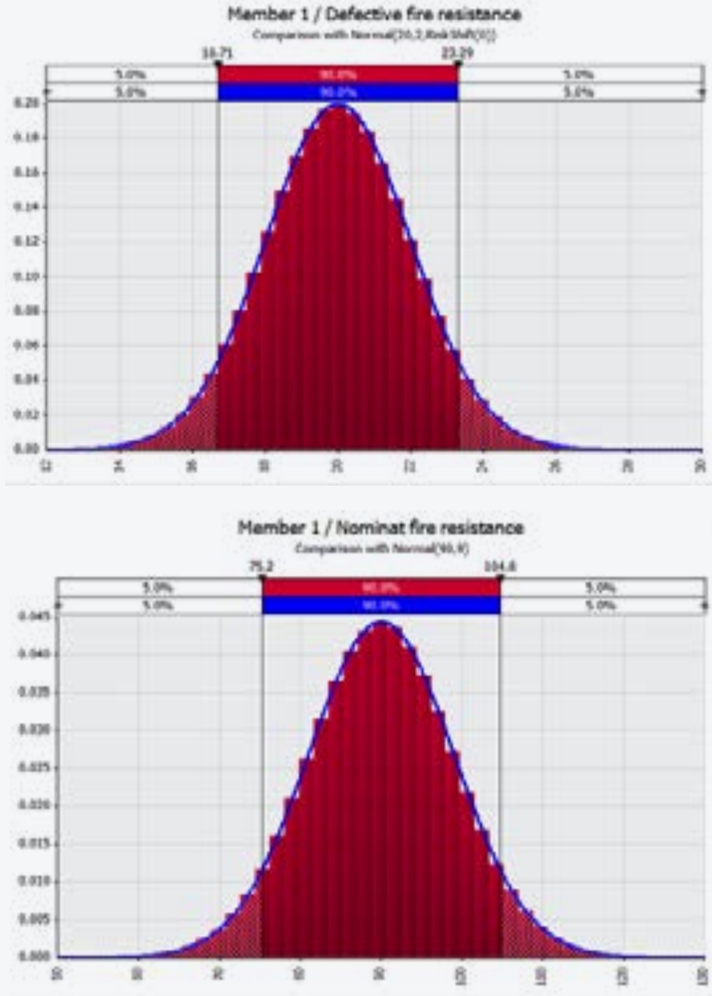


Figure G9: Example schematic layout of an enclosure.

The nominated FRL for the elements is 90/90/90 minutes and a standard deviation of 10% (9 minutes) is assumed for minor variations in performance. The probability of a gross defect is assumed to be 0.01 for each element. With a gross defect the FRL is reduced to a mean value of 20/20/20 minutes with a standard deviation of 10% (2 minutes). The assumed normal distributions are shown in Figure G10.

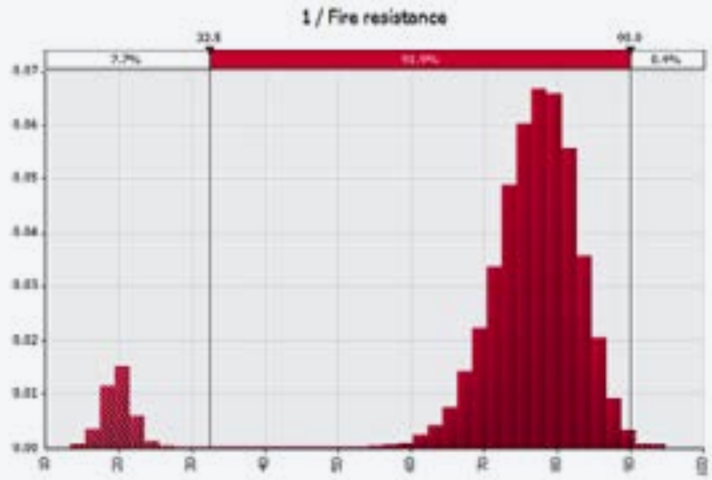


Probability v Fire Resistance Level – min with gross defect

Probability v Fire Resistance Level –min for nominated Fire Resistance Level

Figure G10: Inputs for calculation of combined distribution for simulations.

These two distributions can be combined in a Monte Carlo analysis and distributions obtained for the earliest time to failure of one element. If the time to failure of two or more elements bounding the enclosure is of interest, for example to estimate the time of a major structural failure, this can also be calculated. The results for one and two elements failing are shown in Figure G11. It should be noted that these values are for demonstration purposes and other values were used in the analysis.



Combined distribution for premature failure due to failure of 1 element only (no redundancy)

Combined distribution for premature failure due to failure of at least 2 elements (1 level of redundancy)

Figure G11: Calculated combined distributions for Monte Carlo simulations.

These results can be checked by assuming a binomial distribution using the following equation:

$Pr(X=i)={}_nC_i p^i q^{n-I}$

where

$Pr(X=i)$ is the probability that there will be i successes

n is the number of independent trials

p is the probability of success for each trial, and

${}_nC^i$ is Combinatorics “Choose” function.

This relationship assumes independent trials. It could be argued that if there is one gross defect in a building it could be symptomatic of poor workmanship and supervision and, in such cases, the probability of a second fault being present may be greater. However, with good workmanship and supervision throughout the building, as required by the relevant building regulations throughout Australia, it was considered reasonable to assume independence.

Table G3 presents the probability mass function calculated in accordance with the above function for the case where there are eight primary members around a fire compartment (n=8) and the probability that the fire protection is applied correctly is 0.99 (p=0.99).

Table G3: Probability mass function for eight structural members.

Num columns ok (i)		Prob(X= i)	Prob (X≥i)
0	Pr(X=0)	1E-16	
1	Pr(X=1)	7.92E-14	
2	Pr(X=2)	2.744E-11	
3	Pr(X=3)	5.434E-09	
4	Pr(X=4)	6.724E-07	
5	Pr(X=5)	5.326E-05	0.9999993
6	Pr(X=6)	0.0026361	0.9999461
7	Pr(X=7)	0.0745652	0.9973099
8	Pr(X=8)	0.9227447	0.9227447
Checksum		1	

The probability of any one element failing prematurely can be calculated to be about 1 – 0.923 = 0.077 (i.e.7.7%), and the probability of two or more elements failing prematurely would be 1 - 0.9973 = 0.0027(0.27%), which are consistent with the secondary peaks in Figure G11.

G2.2 Estimates of impact of defects and frequency of occurrence

General variability/primary peak

Factors 2 to 5 in Table G3, together with the variabilities of the properties of the structural element and applied load, were grouped and represented as a normal distribution with a mean value equal to the nominated FRL and standard deviation of 10% of the nominated FRL.

Factor 1 could yield FRLs substantially below the mean FRL and were therefore represented by a secondary peak. The FRL of the secondary peak and probabilities were derived as detailed below. The impact of Factor 6 service penetrations can be allocated to the primary and/or secondary peaks depending upon the specific circumstances which are discussed below.

Probability of gross defects to fire protection systems protecting structural steel or timber

A typical gross defect would be a substitution of fire-protective coverings with non-fire-protective coverings encapsulating steel or timber structural elements and/or forming the boundary of a compartment. Typically, these omissions are expected to occur above false ceilings and behind false walls where they are not easily observed and would be difficult to observe by inspection.

There are very few surveys on which to base an estimate of the probability of such an occurrence. However, a survey of fire safety systems in high-rise office buildings in Melbourne was reported by Moinuddin and Thomas[14]. A sample of seventeen different buildings was considered and, since participation was on a voluntary basis, the results would be expected to be above average in most respects. Results were based predominantly on reviews of maintenance/inspection records. Of this sample, data with respect to structural steel protection was available on two buildings and the results are summarised in Table G4 extracted from the Moinuddin and Thomas paper.

Based on these two data points the number of gross defects per floor would be between 0.06 and 0.136. The report does not identify the sizes of the buildings. A typical steel-framed office approximately 63 m x 27 m could be expected to have of the order of 90 beams/floor. Using this estimate, the frequency of a gross defect would be about 0.0007 to 0.0015/element.

This range is substantially less than the assumed probability of gross defects per element of 0.005 assumed for the analysis.

Table G4: Survey results gross defects for structural steel elements.

Building Ref	No of floors	No of reports available	No of reports showing compliant	Problems reported
1	44	4	2	Report 1: At 6 locations the beams were found to be not protected Report No 2: Non-compliant (no specific details)
2	18	1	0	Fire-rated beam missing from a steel beam

Performance of timber-framed construction with gross defects

Within a residential apartment, it is unlikely that major defects such as direct exposure of unprotected structural framing would occur in occupied areas, but unprotected members may occur behind standard-grade plasterboard. This will be considered to represent a typical gross defect and a similar arrangement will be assumed for structural steel members whereby unprotected steel will be assumed to be concealed behind standard plasterboard sheets. It will be assumed that the plasterboard will provide the equivalent of an additional 10-minute FRL period in addition to the inherent resistance of the base structural member, which is consistent with the assigned contribution of 10 mm (3/8 inch) standard plasterboard[53].

It is therefore necessary to quantify the performance of unprotected timber-frame members. In 1982, a program of tests was undertaken on residential floor constructions using the ASTM E119 (similar to AS 1530.4 standard heating regime) in addition to a proposed alternative heating regime for residential fires[54], as shown in Figure G12.

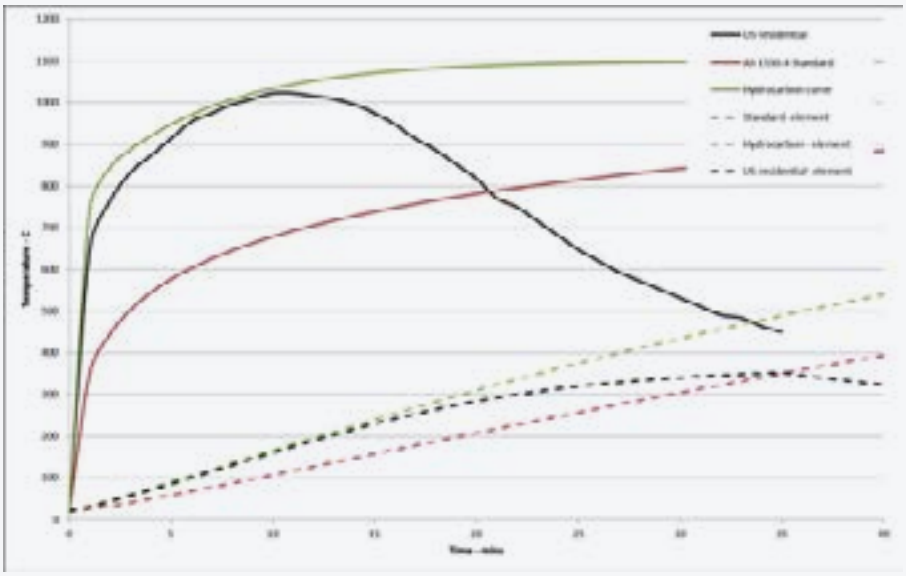


Figure G12: Graph showing NBS proposed residential heating regime with the AS 1530.4 standard and hydrocarbon heating regimes for comparison together with the calculated temperature of a target element.

In the test series, two tests were performed following the ASTM curve on an unprotected floor with 51 mm x 203 mm timber joists with structural failure estimated to occur after 14 minutes and 42 seconds in the first test and 13 minutes 10 seconds in the second test (average approx. 14 minutes). A test was performed following the proposed alternative heating regime on a similar element with failure occurring after 8min 45s. Using the conversion method described in Appendix G3: Converting Fire Resistance Time to Fire Scenario Time, a failure time of 9 minutes was predicted for the proposed alternative heating regime based on standard fire resistance failure time of 14 minutes, providing confidence in the application of the conversion method for deriving scenario times presented in Appendix G5 for low fire durations and unprotected timber members.

During the test series an unprotected lightweight steel joist was also tested with a structural failure time estimated to be 2min 48s.

The results of tests comparing the performance of engineered and more traditional solid joists exposed to the standard ASTM E119 heating regime but with failure conditions based on estimated fire fighter breach were reported by Kerber[55] and are summarised in Table G5.

Table G5: Summary of relevant results from Kerber[55].

Structural Element	**Ceiling**	**Fire Fighter Breach – min: sec**
51 x 250 solid joist	No	18:35
Timber I Joist	No	6:00
51 x 250 solid joist	12.5 mm standard plasterboard	35.30
Timber I Joist	12.5 mm standard plasterboard	26:43
Metal Gusset truss floor	12.5 mm standard plasterboard	29:00
Finger Joint truss floor	12.5 mm standard plasterboard	26:39

Su et al.[56] undertook a series of basement fire tests with representative fire loads with unprotected solid timber and engineered timber members exposed directly to the fire conditions. A series of 11 tests are reported (eight undertaken with the door open and three with the door closed, modifying the ventilation conditions and fire severity). Typical heating regimes for both these scenarios are shown in Figure G13 and Figure G14 for the door open and door closed configurations, respectively. The figures also include the AS 1530.4 Standard heating regime for comparison and calculated temperatures of a target specimen which was used to convert the structural failure times to an equivalent fire resistance time following the procedures described in G3 Converting Fire Resistance Time to Fire Scenario Time.

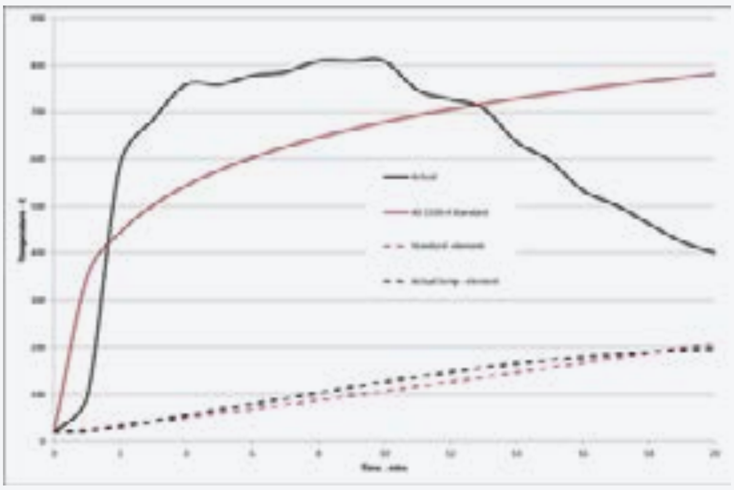


Figure G13: Typical heating regime from studies of unprotected floor assemblies – Door open (Su et al.[56])

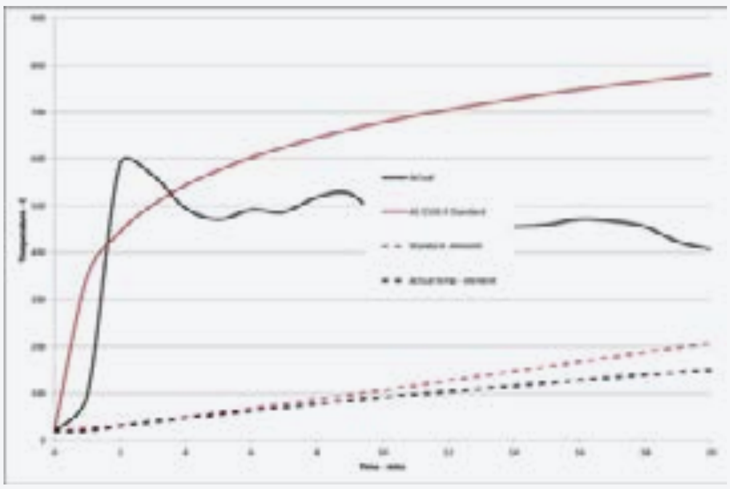


Figure G14: Typical heating regime from studies of unprotected floor assemblies – Door closed (Su et al.[56])

The results for a range of unprotected joists are summarised in Table G6. The repeatability of the results and consistency of the equivalent fire resistance period calculations are very good considering the differences in heating regimes for the door open and closed tests.

Table G6: Time to structural failure and equivalent fire resistance time for unprotected joists from Su et al.[56]

Floor Assembly Type	Test Ref	Door status	Structural failure time – min:s	Equivalent fire resistance time – min
Solid wood joist	UF-01	Open	12:20	14
	UF-02	Closed	20:00	14
Wood I-joist A	UF-03	Open	8:10	10
	UF-09	Closed	12:58	10
Steel C-joist	UF-04	Open	7:42	9
Metal–Plate wood truss	UF-05	Open	7:47	9
Wood I-joist-B	UF-06	Open	6:22	8
	UF-06R	Open	6:20	8
	UF-06RR	Open	6:54	8.5
Metal web wood truss	UF-07	Open	5:25	6.5
	UF-08	Closed	7:64	7

The above results indicate that unprotected solid timber joists will maintain structural adequacy for equivalent fire resistance periods of between 14 and 18 minutes compared to engineered lightweight timber joists, with equivalent fire resistance periods ranging from 6 mins to 10 mins. Lightweight steel joists achieved equivalent fire resistance periods for structural adequacy of 3 to 9 minutes.

The equivalent fire resistance periods for timber-framed beams (allowing 10 minutes for a covering) will be between 16 and 28 minutes, and therefore a mean value of 22 minutes will be adopted; with a standard deviation of 2.2 minutes, such that the estimated range of values will be included within three standard deviations of the mean.

For timber-framed walls, a gross defect would be a frame covered with a single layer of 10 mm or 12 mm non-fire-grade plasterboard, which would provide FRLs consistent with the above estimate of a mean value of 22 minutes with a standard deviation of 2.2 minutes.

Performance of massive timber with gross defects

The fire resistance performance of the massive timber element with a gross defect will be the sum of the inherent fire resistance of an unprotected element plus 10 minutes to allow for the partial protection of a covering. From a review of CLT test data the inherent fire resistances of the CLT tested systems can be estimated to lie in the range of 45 mins to 178 mins, excluding any contribution from a 10 mm plasterboard covering. A reasonable estimate of the performance of a CLT system with gross defects providing the element is greater than 75 mm thick, would be an equivalent fire resistance period of 60 minutes with a 10% standard deviation, assuming a normal distribution subject to adequate detailing of connections. This estimate is also consistent with the typical performance of a massive timber element with a fire-protective covering of 16 mm fire-grade plasterboard required to achieve an FRL of 90/90/90, if a 30 minutes contribution to the FRL is provided by the plasterboard and 60 minutes is provided from the inherent fire resistance of the massive timber element.

Performance of structural steel elements with gross defects

As discussed above, the impact of gross defects on the combined slab/beam assembly will be based on the performance of the steel beams. Adopting a consistent approach to that proposed for the timber-frame building, it will be assumed that fire protection has been omitted above a false ceiling or behind a false wall or column encasement. Therefore the time to failure assuming a gross defect will be based on the FRL for unprotected steel plus 10 minutes. The FRL of unprotected steel will be calculated using the correlations from AS4100 presented below and adopting a critical temperature of 550°C.

Equation 2 – three-sided exposure $t = -5.2 + 0.0221T + (0.433T/k_{sm})$
Equation 3 – four-sided exposure $t = -4.7 + 0.0263T + (0.213T/k_{sm})$

where

t = time from the start of the test, in minutes
T = steel temperatures, in °C ($500°C \leq T \leq 750°C$)
k_{sm} = exposed surface to mass ratio, in m^2/tonne ($2 \leq k_{sm} \leq 35$)

For mid-rise buildings, common sections would be expected to have surface area to mass ratios in the range of 18 to 30m²/tonne. Table G7 shows the calculated fire resistance assuming a limiting temperature of 550°C for this range of sections.

Table G7: Calculated fire resistance for unprotected steel sections.

k_{sm} -	**Fire Resistance – min**	
m²/T	three-sided	four-sided
18	20.2	16.3
19	19.5	15.9
20	18.9	15.6
21	18.3	15.3
22	17.8	15.1
23	17.3	14.9
24	16.9	14.6
25	16.5	14.5
26	16.1	14.3
27	15.8	14.1
28	15.5	13.9
29	15.2	13.8
30	14.9	13.7

For the purposes of this analysis, an equivalent fire resistance time for failure of a structural steel member with gross defects will be taken as 26 minutes (this includes a 10-minute allowance for standard plasterboard or similar coverings) with a standard deviation of 10%. With this assumed distribution, all the common values will lie within two standard deviations of the mean.

Performance of lightweight steel elements with gross defects

Test data from lightweight steel construction indicates that lightweight steel-frame construction may be more sensitive to changes in heating rates than timber-frame construction, due to the higher coefficient of thermal expansion and small cross-section increasing the risk of premature degradation of fire-protective coverings.

Since a comparative analysis is being undertaken to consider the extension of the use of timber-frame construction, it will be assumed that the method to convert fire resistance times to fire scenario times is applicable to lightweight steel-framed walls and the impact of gross defects will be similar to lightweight timber-framed construction, since such an approach will yield conservative results (ignoring potentially poorer performance of lightweight steel-frame construction compared to timber).

It will also be assumed that lightweight steel floor/ceiling systems will not be used in the control building and that structural steel will be adopted for the loadbearing frame. This approach has been adopted to provide a higher benchmark by ignoring lightweight steel floors, which tend to achieve similar or worse performance than lightweight engineered timber systems when unprotected.

Gross defects to reinforced concrete and masonry elements

Gross defects for reinforced concrete could include:

- no or minimal cover to reinforcement
- missing or insufficient reinforcement
- large openings in inaccessible places
- concrete and detailing increasing risk of excessive spalling.

Merretz[57] summarised the findings of a survey of 95 buildings in the Sydney area, which focused on durability. Of the 227 faults detected, the average cover was found to be 5.45 mm. Typically, at least 20 mm or more minimum cover is required to satisfy durability requirements. Such variations could have a very large impact on the fire resistance performance of concrete elements.

For masonry gross defects could include

- missing bricks /blocks in inaccessible places
- walls too slender / inadequate end restraint

Since the control building is predominantly of steel-frame construction a detailed analysis of the impact of gross defects relating to concrete has not been undertaken since the impact of gross defects will be based on failure of the steel beams supporting the slab due to omitted fire protection.

Service penetration defects

A report on the fire system effectiveness in major buildings in New Zealand[13] included inspection data from university, hospital, and office/retail buildings relating to more than 5,000 passive fire protection systems including service penetrations, which are summarised in Table G8.

Table G8: Summary of NZ inspections of service penetration seals.

System	Issue	% of cases in drywall systems (e.g. plasterboard)	% of cases in masonry walls	Ratio of drywall: masonry wall construction
Small penetration (e.g. single cable)	Unsealed	16.2	18.4	0.88
	Incorrect sealant	2.7	2.1	1.29
	Total	**18.9**	**20.5**	**0.92**
Large penetration (e.g. cable tray)	Unsealed	40.0	33.3	1.2
	(e.g. cable tray)	20.0	8.3	2.4
	Total	**60**	**41.6**	**1.44**
Collar system	Missing	10.8	8.3	1.30
	Incorrect installation	7.7	6.3	1.22
	Ad hoc arrangement	5.4	4.2	1.29
	Total	**23.9**	**18.8**	**1.27**

From Table G8, the frequencies of issues and types of faults with penetration seals in masonry and drywall systems are broadly similar. It cannot be ascertained if the higher frequency for plasterboard systems is a trend or just a result of the small sample size.

The 'ad hoc arrangements' category is assumed to represent penetrations that are sealed but there is insufficient documentation to determine the adequacy of the system. It will be assumed that the performance of these types of system will be reflected in the distributions assumed for the FRLs of the base elements of construction, and the ad hoc systems have therefore been excluded from requiring specific consideration. Table G9 shows the percentage of penetration seals with potentially significant defects from the New Zealand Study.

Table G9: Seals with potentially significant defects (derived from Table G8).

System	% of cases in drywall systems (e.g. plasterboard)	% of cases in masonry walls
Small penetration (e.g. single cable)	20	20
Large penetration (e.g. cable tray)	40	33
Collar system	19	15

These results were not obtained from apartment buildings and therefore the applicability of the data needs to be considered. In apartment buildings, the following conditions will generally apply:

- Large penetrations will generally be restricted to service risers and will therefore not be from one occupied area to another.
- Small penetrations will occur for the main power supply, telecommunications systems, sprinkler system and water supply.
- Plastic soil waste and vent pipes will be in common usage and require protection, usually employing intumescent seals in collar assemblies.
- Typically, service penetrations will occur in clusters in bathrooms/toilets and kitchen areas, and will penetrate service risers with low internal fire loads.

Defective service penetration seals can reduce the effectiveness of barrier systems. The degree to which this occurs depends on a number of factors including:

- the size of service penetration
- the type of service penetration
- the position of the service penetrations
- the separating element penetrated.

Considering the generic apartment building, the services penetrations will tend to be in three clusters around the bathrooms and kitchen areas, which are served by risers that contain only services with a limited fire load, reducing the risk of spread to other habitable spaces.

The probability and/or consequences of fire spread due to faults with small service penetrations is expected to be relatively low compared to large penetrations/plastic pipe penetrations.

Where collar systems are missing, there is a greater potential for large openings and premature fire spread to occur and/or structural adequacy to be impacted but, in many instances, the adjacent compartment may be a service shaft where the potential for fire spread would be limited by the low fire load. Since this mode of failure could impact considerably upon the size of the secondary peak in the two peak model if there is a large reduction in the FRL, an experiment was undertaken to gain an understanding of the impact of large unprotected service penetrations on timber-framed construction[58]. A nominally sized 3 m x 3 m wall system was constructed with two 90 x 45 timber stud frames faced with two layers of 13 mm thick fire-grade plasterboard on the occupancy sides of the studs. Mineral fibre insulation was fitted between studs on the non-fire side of the cavity. The party wall arrangement was selected to represent a worse case scenario because fire spread was unrestricted within the cavity, whereas the cavity was closed off with single-frame wall systems by the noggins limiting incipient fire spread. The specimen was penetrated by an unprotected 100 mm uPVC pipe, which passed through the wall to a plasterboard shaft on the non-fire side.

A load was applied to the fire-side timber frame during the test avoiding load sharing with the non-fire side frame. The specimen supported the full test load for 72 minutes, which is about two standard distributions from the mean if a 10% value for the standard distribution is assumed.

Temperatures measured on the surface of the uPVC pipe during the test close to the point where it penetrated the shaft indicated that fire spread could occur after about 5 minutes equivalent FRL period if there was a direct service penetration between occupied areas. This type of detail would, however, run through a service shaft in most installations to address noise control issues as well as fire protection.

The control building also included drywall components with steel studs compared to timber studs and, since a comparative study is being undertaken, similar performance for the control and timber-framed buildings would be expected.

Based on the above discussion, it was considered that the assumed two-peak FRL distribution will incorporate the effect of defects relating to service penetrations.

Openings in lift shafts and fire-isolated stair shafts

Moinuddin and Thomas[14] reported findings from maintenance inspections on three office buildings estimating a 16% likelihood of there being a gap/hole in each fire stair. No gaps/holes were reported in the lift shafts of the three buildings.

Considering the generic apartment building, it can be assumed that approximately three elements/floors bound the stairs or lift shaft (2 SOUs and a public area), which equates to 24 elements. Therefore, the probability of an element bounding a stair having an opening would be 0.007, which appears reasonable when compared to the estimates of the probability of openings through SOU bounding construction (0.021 to 0.03).

If unprotected openings in the shaft wall occur, the shaft will tend to fill with smoke in a similar manner – irrespective of the form of construction – if the impact of sprinklers is ignored and, under these circumstances, the consequences would be similar.

G2.3 Summary of Inputs for FRL Two Peak Distributions

The proposed inputs to the Monte Carlo analysis are summarised in Table G10.

Table G10: Fire resistant inputs for Monte Carlo simulations.

Element	Case	FRL – min	SD – %	Prob. of defect	Defect FRL – min	SD – %	Levels of redun-dancy	Notes
Apartment Fire doors and fire stair doors	All	60	10	.1 (.05)	0	0	0	Bracketed value relates to door to apartments other than fire apartment. Defects covered in 'door open' configurations
Service penetrations								Impact of unprotected service penetrations assumed to be in primary peak
Global structural collapse; loadbearing walls and floor/ceilings	Control Massive TF	90	10	.005	26 60 22	10	1	Impact of unprotected service penetrations assumed to be in primary peak
Non-loadbearing walls	Control Massive TF	60 75 75	10	.005	22 60 22	10	0	Requirements to control incipient fire spread are expected to typically provide 90 minutes FRL for TF but period has been downgraded to 75 minutes to allow for unexpected systems. Inherent FR of massive timber plus covering are expected to provide FRLS in excess of 75 minutes

Note: a single time (most critical) has been nominated for FRLs rather than separate values for structural adequacy, integrity and insulation. For example, 60 minutes has been specified for fire doors since the 30-minute insulation criteria is not considered significant for predicting fire and smoke spread.

G3 Converting Fire Resistance Time to Fire Scenario Time

In most instances, the time to failure of an element of construction ascertained in a standard fire resistance test will differ from the failure time if the element is exposed to a real or simulated fire scenario (e.g. Annex A of EN 1991-1-2:2002) because the time temperature histories will differ (see Figure G15).

If an element of construction comprises homogeneous materials with known thermal and mechanical properties at elevated temperatures (e.g. steel, concrete, timber), it is possible to determine the time to failure using simple correlations or more complex methods such as finite element analysis.

However, many fire-resistant elements or components are too complex to model reliably (such as fire doors, penetration seals, composite systems, connections, board fixings, adhesion of sprayed materials, spalling of high-strength concrete, etc) and therefore a general method for conversion of fire resistance times to scenario times was preferred. This also addressed concerns that different models are likely to have varying degrees of conservatism generating further variables in the analysis.

A detailed review of general time equivalency methods has been undertaken by Wade et al.[59] The review recommended the use of an energy-based time-equivalent approach as a general method to assess the performance of building elements exposed to compartment fires of different severities based, on Kodur's Equivalent Absorbed Energy Method[60].

Time equivalence based on the maximum temperature of protected steel was discounted in the Wade study on the basis that equivalency could only be ascertained if maximum temperatures are achieved. However, a method based on Equal Steel Temperature (EST) can be developed that does not rely on a maximum temperature being attained as detailed below:

$$\Delta T_s = \frac{k_i}{h}\left[\frac{(T_f - T_s)}{c_s\left(W/D\right) + \frac{c_i \rho_i h}{2}}\right]\Delta t$$ **Equation 4**

A 'target protected steel element' is defined with known thermal properties and the temperature at a critical point calculated when exposed to the fire scenarios and the standard heating regime. Equivalent exposure is deemed to have occurred when the critical part of the element reaches the same temperature under the different heating regimes. In this case, a lumped thermal mass approach was adopted with the mean temperature of the steel calculated using Equation 4[61] .

Where:

T_s is the steel temperature – °C

T_f is the enclosure temperature – °C

k_i is the thermal conductivity of the insulation W/m.K

c_i is the heat capacity of the insulation – K/kg.K

ρ_i is the density of the insulation –kg/m^3

c_s is the heat capacity of steel – J/kg.K

W/D is the mass per unit length divided by the heated perimeter kg/m^2

Δt is the time step – s

The process is shown graphically in Figure G15. If it is required to determine the time to failure of an element that achieved an FRL of 63/-/- when exposed to the fire scenario (parametric curve) fire, the following approach is adopted:

- the target element attains a temperature of 454°C when exposed to the standard fire resistance test for 63 minutes
- the target element would need to be exposed to the fire scenario for 45 minutes to attain the same temperature
- therefore the fire scenario failure time would be 45 minutes.

In this example, the target element would need to be exposed to the hydrocarbon heating regime for 45 minutes to attain 454°C.

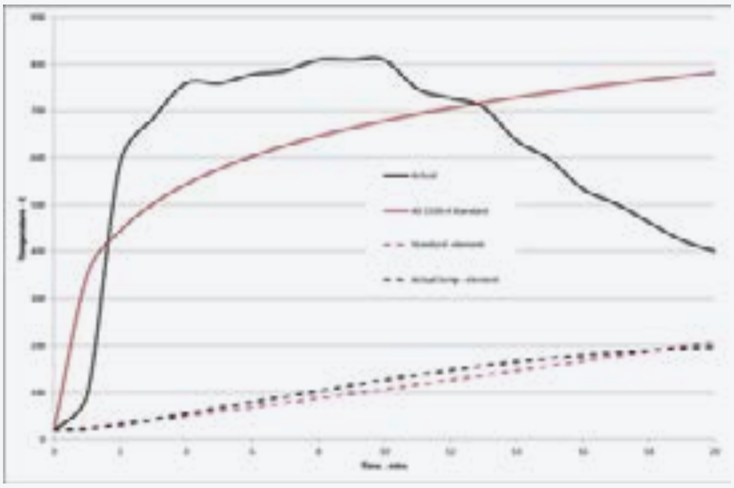


Figure G15: Conversion of fire resistance period to fire scenario time.

Three candidate methods were considered to convert fire resistance times to scenario times and vice versa based on the above discussion:

- Nyman's Method using the emissive power of Fire Gases
- Kodur's Equivalent Absorbed Energy Method
- Equal Steel Temperature (EST method) described above.

The methods were compared by using each one to convert the standard heating regime to an equivalent hydrocarbon heating regime time and then plotting results from tests on the same forms of construction that had been fire tested to both heating regimes. The data obtained for this purpose is summarised in Table G11.

The results of the comparison are summarised in Figure G16. The absorbed energy (without the modification factor) and imposed radiation methods provide comparable results (as shown in Figure G16) and tend to underestimate the hydrocarbon heating regime time compared to experimental data. Since a comparative study is being undertaken, it is preferable to estimate performance as accurately as possible. Kodur et al. calibrated their method against deflections estimated from finite element analysis and proposed a correction factor based on maximum temperature reached. For the hydrocarbon regime, a factor of 1.16 was therefore applied, improving the correlation with experimental data. Results for the Kodur method are shown with and without the correction factor derived from finite element analysis of concrete beams.

With respect to the EST method, three thicknesses of material were considered with properties approximating to ceramic fibre. The input data used is summarised in Table G12. As expected, different correlations were obtained depending upon the thickness of fire protection assumed when using the EST method. This was also reflected in the calculations based on large test programs involving loaded and unloaded steel sections protected by a sprayed vermiculite system. It is therefore important to select a material thickness representative of the fire resistance range and protection thicknesses relevant to the study. In this instance, the steel target protected by a 25 mm thickness of material with properties approximating to ceramic fibre was found to provide the most reliable conversion and was therefore adopted for the detailed analysis.

The main limitation with the above method is that it considers thermal performance only but does not directly consider the impact of factors such as thermally induced deflections and/or stresses, degradation of structural materials and materials used for protection (e.g. spalling, shrinkage, thermal shock and critical chemical reactions).

If the standard fire resistance heating regime is representative of typical fully developed fires, then the above issues may not require further consideration, but the increased use of plastics in modern furnishings and increased fuel loads among other things have tended to increase the rate of fire growth[55,62].

Table G11: Comparative data for elements exposed to standard and hydrocarbon heating regimes.

Data Sources	Type of Construction	Data used
FWPA 13 timber frame: **F91769**[63] **F91770**[64] **F91767**[65] **F91768**[66]	90 x 45 mm timber studs faced with one layer of 13 mm Australian fire-grade plasterboard non-loadbearing	Interface temperatures 300°C and stud temperatures at 7.5 mm depth 300°C
FWPA 26 steel frame: **F91780**[67] **F91782**[68] **R9112**[69] **R9113**[70]	64 mm steel stud faced with two layers of 13 mm Australian fire-grade plasterboard – non-loadbearing small scale	Upper surface of plasterboard face. Insulating pads fitted as appropriate – time to 300°C
Spray protected steel	Linear regressions of results from steel test packages undertaken on the same product to the standard and hydrocarbon heating regimes yielding correlations for fire resistance time as a function of surface area to mass ratio, and protection thickness	Comparable results generated using regression coefficients for a spray steel protection system
Solid core door: **Young and England**[18]	Comparative tests performed with corridor mounted in front of solid core timber doors fitted with smoke and intumescent seals	Time to low visibility
Concrete: **Faris et al.**[71]	Comparative tests performed on concrete slab sections under load	Reinforcement 100°C Time to 32 mm deflection
Concrete: **Cooke**[72]	Comparative tests	Deflection

Note: Results for the concrete test reported by Faris were not reported beyond 60 minutes; therefore, only limited comparative data was available.

Table G12: Input Data for EST conversion model.

Parameter	Value(s)	Units
Thickness	10,15,25	mm
Thermal conductivity (insulation)	0.2	W/mK
Heat capacity (insulation)	1000	J/kg/K
Density (insulation)	96	kg/m^3
Heat capacity (steel)	550	J/kg/K
Mass/unit length of steel section	59	kg/m
Heated perimeter	1.21	m

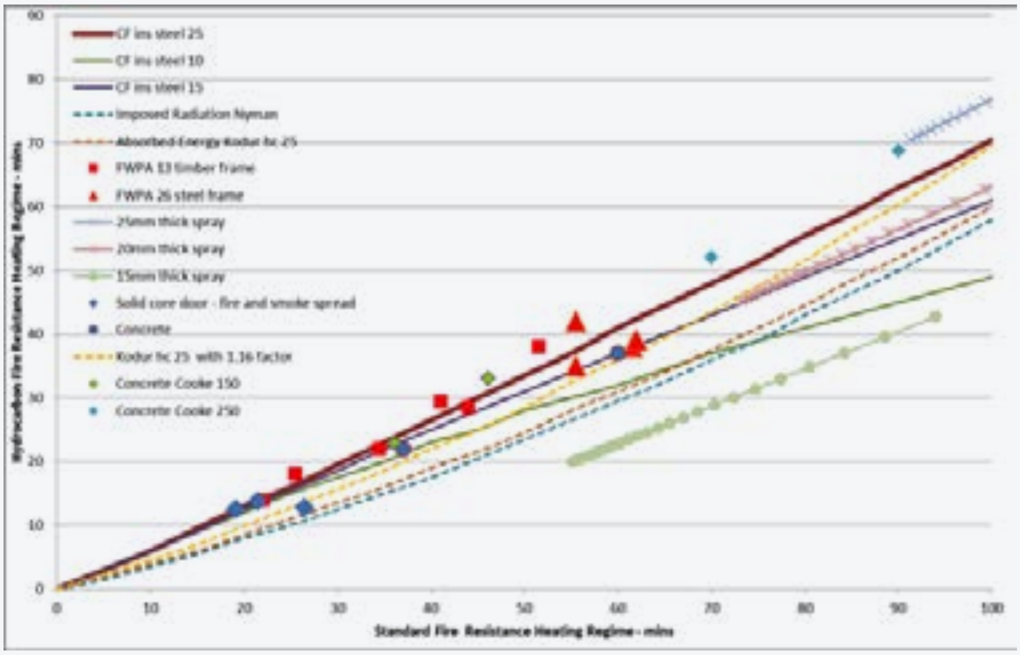


Figure G16: Comparison of conversion methods for standard and hydrocarbon fire resistance test heating regimes.

The following approach was adopted to address the above limitations:

1. The NCC 2016 requirements retain the requirement for the fire resistance of protected timber to be determined in accordance with the standard fire resistance test (AS 1530.4) and also require additional measurements for resistance to incipient spread of fire, for example. Specimens are tested at a representative size (typically 3 m minimum dimension) and, if loadbearing, under loaded conditions. The same requirements also apply to elements other than timber. These tests will demonstrate the performance of systems including thermally induced deflections and stresses, degradation of structural materials/fixings and fire protection systems.
2. To further check for sensitivities, comparisons were made against data from tests performed on similar elements of construction under different heating regimes.
3. In some instances, engineering principles can be applied to assess the impact of more severe heating rates. For example, thermally induced deflections will tend to be greater with more rapid rises in temperature. Materials with relatively high rates of thermal expansion will be prone to greater thermally induced deflections, which may cause premature structural failure or open up gaps in fire protection systems (e.g. lightweight steel systems).

Another practical limitation with the standard test method is that it does not monitor performance after the end of the fire test during the cooling phase. This will affect different forms of construction in different ways. For example, timber structural elements may continue to burn if already ignited or may self-extinguish based on the configuration and imposed heat flux; protected steel temperatures may continue to rise after the end of the test due to heat contained in the fire protection material continuing to flow towards the structural member; and concrete and masonry may degrade and sudden collapse may occur when thermally induced restraint conditions change as the element cools. While these limitations apply to most forms of construction, the mid-rise timber buildings require sprinkler protection under the Deemed-to-Satisfy Provisions in the NCC 2016, substantially reducing the frequency of exposure of the structure to fully developed fires, such that this limitation in the standard test method is less important for mid-rise timber buildings compared to non-combustible construction.

G4 Verification of Stair Climbing Component within the implementation of the Fire Brigade Intervention Model used

The stair climbing component of the model was compared against results of international studies summarised by Claridge. Figures G17 to Figure G22 show outputs from the sub-model for times to climb various levels, and Figure G23 shows these results plotted over the international study results.

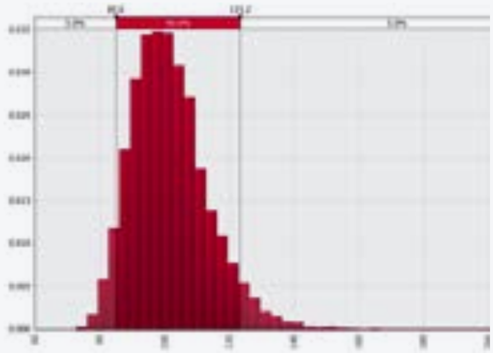


Figure G17: Time to climb 5 levels.

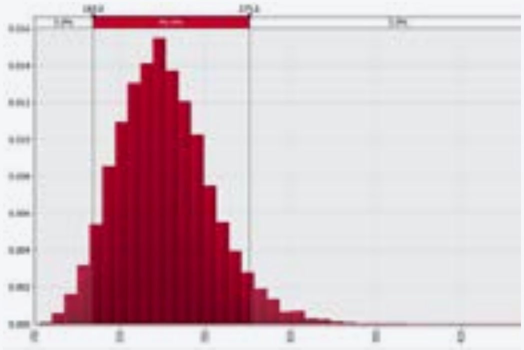


Figure G18: Time to climb 10 levels.

Figure G19: Time to climb 15 levels.

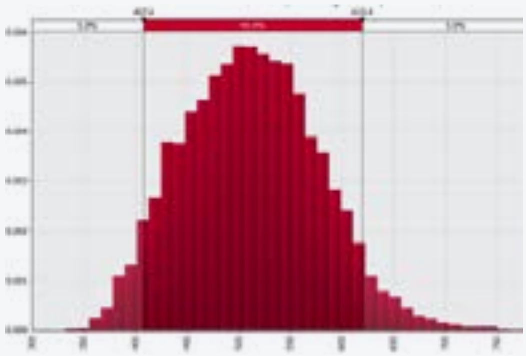


Figure G20: Time to climb 20 levels.

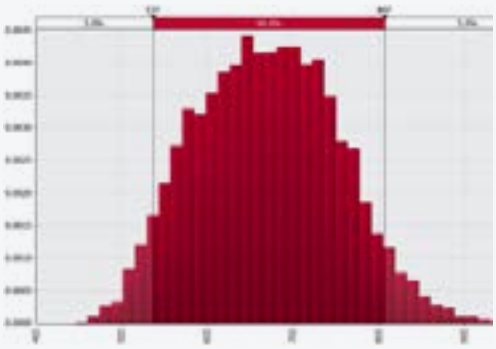


Figure G21: Time to climb 25 levels.

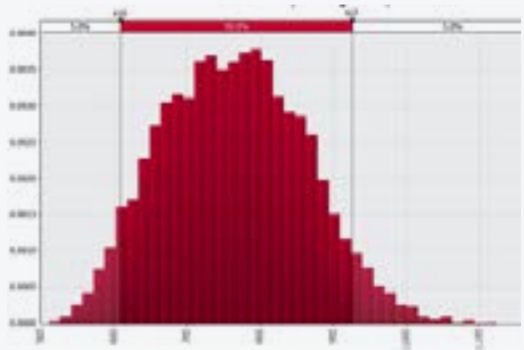


Figure G22: Time to climb 28 levels.

The results correlate well for 5 levels but tend to be conservative at higher levels, which would be expected because of the allowance of recovery periods above 6 levels. It is therefore considered reasonable to adopt the modelling approach and input data for mid-rise buildings.

However, to address the potential for hindrance to fire fighters by evacuating occupants, a 50% increase has been applied to the travel time within the stairs to the set-up position.

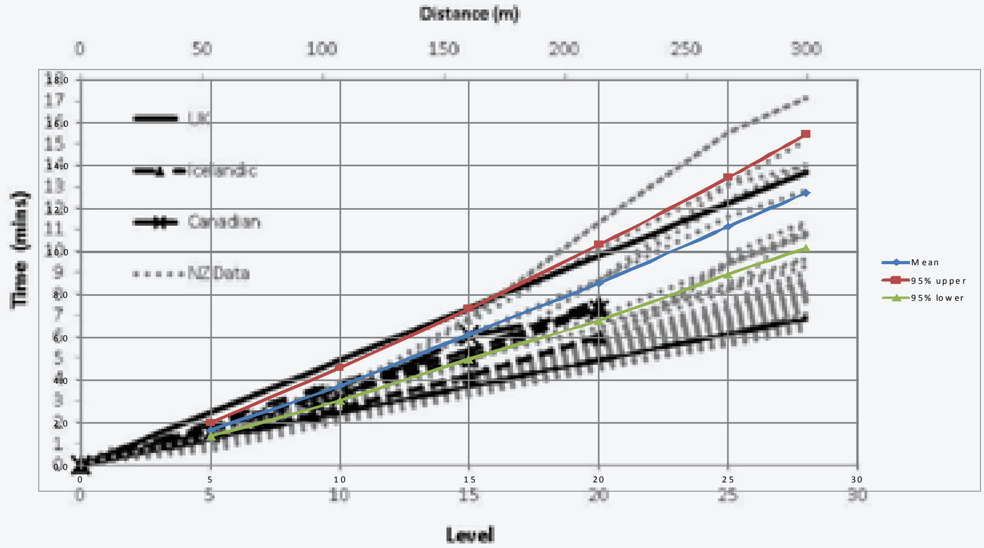


Figure G23: Stair climbing results superimposed on international study results summaries.

G5 Occupant Behaviour Review

A review of international research relating to Occupant Pre-movement Times in Fire undertaken in 2005[73] concluded that, among other things: "At best pre-movement components for specific occupancies could be estimated from statistical analysis and presented in the form of a probability distribution. At present the global database is small and the reliability of predictions based on it (are) likely to be low".

Verification Method C/VM2 prepared to support the New Zealand Building Code[24] nominates the following pre-movement times for buildings where the occupants are considered sleeping and familiar with the building (e.g. apartments):

- Enclosure of fire origin: 60 seconds.
- Remote from the enclosure of fire origin: (standard alarm signal) 0–300 seconds.

The document notes that the incipient phase of the fire growth has not been considered in the design fire, providing an implicit safety factor for the pre-travel activity time.

The above values were also proposed in a draft NCC Fire Safety Verification Method 2015 issued by the ABCB for comment in 2013[74].

Some relevant studies from fire incidents are summarised below:

Wales and Thompson[75] reported the initial stages of Kent Fire and Rescue Service's project to build a comprehensive database of the behaviours and associated motivations of those directly experiencing an accidental dwelling fire. Preliminary findings based on 140 completed surveys include:

- 70% of respondents reported entering the room of fire origin to investigate the source of cues and more than one-third attempted to fight the fire before being driven back by smoke.
- 50% of respondents waited more than one minute before calling the fire brigade (due to occupants trying to fight the fire first).
- After alerting the fire brigade, one group quickly exited alerting others on the wa,y but 40% made some attempt to fight the fire.
- 70% evacuated the building but about 40% re-entered the building for some reason.

While these results relate to single dwellings in the UK they are considered to provide a useful indicator of the likely behaviour during fires in apartment buildings in Australia, in the absence of more relevant and comprehensive data, and have been considered when determining the time the fire brigade are alerted.

Data from post-fire studies indicates that a pre-movement time of 5 minutes may not be conservative for mid-rise and high rise apartment buildings. For example, Proulx and Fahy76 reported average pre-movement (evacuation commencement) times of 2 min: 49 s (5 min: 19 s in winter) and 8 min: 35 s for residential buildings with good and poor alarms, respectively. These are significantly less than the delays in the Forest Laneway Fire (198 min) due in part to the presence of smoke in evacuation paths and a very poor detection/alarm system. A plot of the frequency against delay time to start evacuation during residential and office drills shown in Figure G24 indicates that after an initial peak there is a long tail, indicating that occupants will be evacuating the building over a lengthy period.

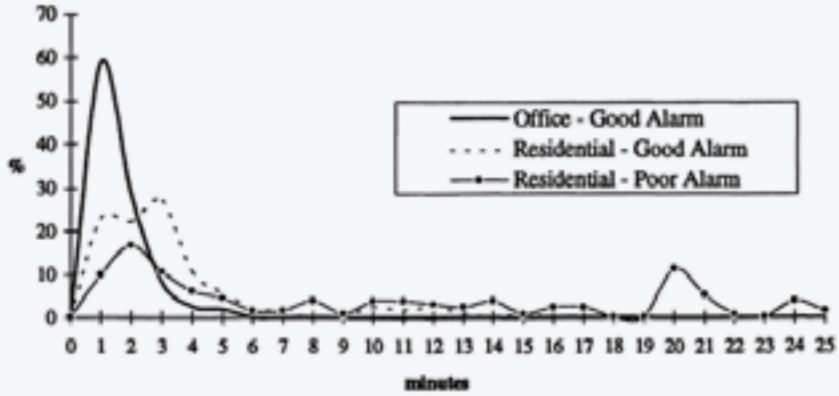


Figure G24: Delay to start evacuation during residential and office fire drills from Proulx and Fahy.

A similar but flatter distribution occurred in the Forest Laneway Fire during the first 30 minutes of the fire, as shown in Figure G25, after which evacuation could not be achieved due to fire/smoke spread, with most occupants waiting in the relative safety of their apartments. There were approximately 550 occupants at the time of the fire.

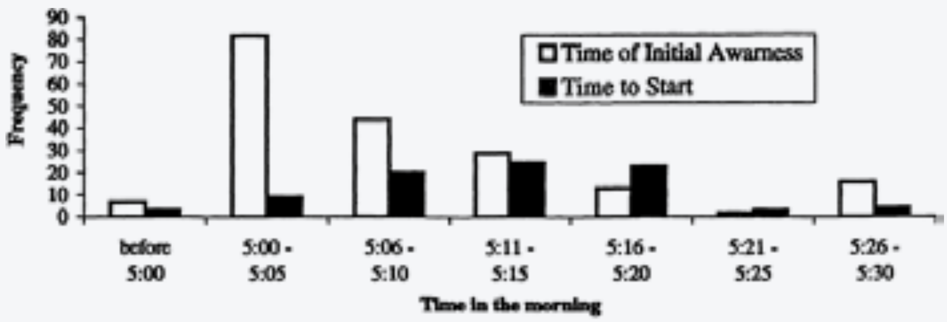


Figure G25: Time of initial awareness and time to start evacuation for the first 30 minutes of the Forest Laneway Fire from Proulx and Fahy.

An analysis was undertaken of an 8-floor apartment building fire that occurred in Rinkeby, Sweden, in 2009 with parking on the ground/basement level[77]. The building was concrete-framed with brick or lightweight concrete walls with mineral fibre insulation with a fire resistance of at least 60 minutes, and 60-minute fire doors providing direct access from the apartments to the stair. There were 12 apartments housing a total of about 33 people at the time of the fire. The fire started on the lower level of a second-level apartment and spread through an open door to the stairwell. Seven fatalities occurred in the stairwell prior to fire brigade arrival. All were trying to evacuate the 7th floor.

All occupants, with the exception of one who was asleep, initially tried to evacuate via the stairs. Some occupants returned to their apartments and awaited fire brigade intervention or climbed down the outside of the building. Others tried to evacuate through the smoke and flames in the stairwell. Of these, some were successful, but seven people perished between the 3rd and 4th levels of the stairwell on the way down from the 7th floor.

This demonstrates typical behaviour; whereby, most occupants at some stage try to evacuate a building once they realise there is a major fire. If they encounter heat and smoke, some will return to apartments and others will try to evacuate through the smoke.

H

Appendix H: Summary of UK Timber Frame 2000 Project – UK

A full-scale fire experiment was undertaken in the UK, as part of the TF2000 project on a six-storey timber-frame building constructed with the platform construction method in 1999, to demonstrate the performance of complete medium rise timber-frame buildings subject to real fires[78]. In particular, the objective of the test was to evaluate fire resistance of a medium rise six-storey timber-framed building subject to a severe natural fire exposure, to ensure that the form of construction can meet the functional requirements for such buildings of the Building Regulations for England and Wales and the Building Standards for Scotland.

The internal loadbearing walls were clad with two layers of standard (non-fire-grade) plasterboard and 9 mm OSB, Type F2 sheathing to one side, where needed for wind bracing. The internal non-loadbearing walls consisted of timber studs with one layer of plasterboard to each side. The compartment walls were a twin stud arrangement with timber studs and mineral wool insulation in between. The structural timber framing and boundary walls of the compartment were protected by plasterboard systems to provide a 60-minute fire resistance (i.e. the equivalent of an FRL of 60/60/60).

The building had four apartments on each of six storeys. The floor plan measured 24.1 m × 12.4 m. The height to the eaves of the building from the ground was approximately 14.4 m. The fire test compartment was a single flat (apartment) on the second floor (level 3) in the southwest corner of the building with a floor area of approximately 60m^2 and a fire load of 391 MJ/m^2 in the form of timber cribs[79].

The fully developed fire did not spread to involve the whole apartment (mainly due to the fire load not being distributed throughout the apartment) but was concentrated within the lounge area and adjacent kitchen. Since the fire was most severe within the living area, the following review will focus on the living area.

Key events following ignition were:

- the fire brigade broke the kitchen window after 22 minutes
- flashover after 25 minutes
- peak temperature close to ceiling in lounge area was about 1020°C after 42 minutes, based on mean of two thermocouples
- door to apartment opened for fire brigade to gain access after 63 minutes (based on observed temperature rise in lobby as door opened)
- temperature close to lounge ceiling approximately 895°C at 59 minutes.
- water applied to the lounge area after 64 minutes by fire brigade
- temperature close to lounge ceiling at 63 minutes just before application of water 730°C
- lounge temperature close to ceiling about 74°C after 68 minutes
- during or after the test, ignition of some timber framing members beneath plasterboard occurred, which was not identified or suppressed at the end of the test. The fire continued to grow within the cavity, eventually leading to the recall of the fire brigade approximately 2.5 hours later.

During the full-scale fire experiment and subsequent cavity fire, the fire did not lead to untenable conditions within adjoining apartments, although damage did occur to the ring beam and studs in the wall to the flat immediately above the fire. Reports refer to some evidence of fire spread to the flat above (presumably flaming from the window frame) but no visible damage to the wall viewed from the apartment was noted.

The following conclusions were provided in the Summary Report[81].

"The compartment fire test met the stated objectives of the programme. The following conclusions may be drawn from an analysis of the data and from observations during and after the test,

- *Derived values of time equivalence have demonstrated that the performance of the complete timber frame building subject to a real fire is at least equivalent to that obtained from standard fire tests on individual elements*

- *Results indicate that fire conditions in the living room of the flat represent an exposure approximately 10% more severe than a standard 60 minute fire resistance test.*
- *The test demonstrated that timber frame construction can meet the functional requirements of the Building regulations of England and Wales and the Building Standards of Scotland in terms of limiting internal fire spread and maintaining structural integrity.*

In meeting the requirements of the regulations and the objectives of the research programme a number of issues have arisen:

- *The standard of workmanship is of crucial importance in providing the necessary fire resistance performance especially nailing of plasterboards.*
- *Correct location of cavity barriers and fire stopping is important in maintaining the integrity of the structure.*
- *The Type of Construction is one that in the United Kingdom has a relatively low market share generally and in the medium rise terms is very recent. For this reason fire brigades are unlikely to be familiar with the type of construction details used. Clearly, education on timber frame for these bodies is necessary.*
- *The issue of vertical flame spread from floor to floor via the windows needs to be addressed."*

The relevant functional requirement is B3[80] which states:

Internal fire spread (structure)

B3.

(1) The building shall be designed and constructed so that, in the event of fire, its stability will be maintained for a reasonable period.

(2) A wall common to two or more buildings shall be designed and constructed so that it adequately resists the spread of fire between those buildings. For the purposes of this sub-paragraph a house in a terrace and a semi-detached house are each to be treated as a separate building.

(3) Where reasonably necessary to inhibit the spread of fire within the building, measures shall be taken, to an extent appropriate to the size and intended use of the building, comprising either or both of the following –

(a) sub-division of the building with fire-resisting construction;

(b) installation of suitable automatic fire suppression systems.

(4) The building shall be designed and constructed so that the unseen spread of fire and smoke within concealed spaces in its structure and fabric is inhibited.

Table H1 summarises the relevant fire safety requirements for the building on which the above conclusions were drawn, compared to the NCC 2016 Deemed-to-Satisfy Provisions.

Table H1: Comparison of fire safety requirements for the Proposal-for-Change and the TF2000 Solution.

System	NCC 2016 DTS Requirements	TF2000 UK system
Loadbearing structural elements	FRL 90/90/90 plus incipient spread of fire criteria applied for 45 minutes	FRL 60/60/60
Non-loadbearing elements	FRL (-/60/60)* plus incipient spread of fire criteria applied for 45 minutes	FRL -/60/60
Cavity barriers	FRL -/45/45	FRL -/30/15
Automatic fire detection and alarm	Required	Required
Cavity insulation required to be non-combustible	Required	Not required
Automatic fire sprinklers	Required	Not required

** Estimated impact of incipient spread of fire criteria is to increase FRL to between -/75/75 and -/90/90 depending upon form of construction*

From examination of Table H1, it can be noted that for the NCC 2016 DTS requirements:

- Protection levels to timber members have been increased, reducing the risk of fire spread to cavities.
- Incipient spread of fire criteria are also applied. Under the 2014 version of AS 1530.4, this includes enhancements for service penetration test methods in elements required to be resistant to incipient spread of fire.
- There are enhanced requirements for cavity barriers to address risk of spread should a fire initiate or spread to cavities.
- There are enhanced controls on cavity insulation materials to reduce the risk of spread via cavities.
- There is provision of automatic fire protection systems, greatly reducing the probability of flashover fires occurring and hence greatly reducing the risk of fire spread vertically between windows, in line with current NCC approaches for sprinkler-protected buildings.

Based on the above discussion, it can be observed that the NCC 2016 mid-rise timber building DTS requirements provide significantly higher levels of protection than the TF2000 building, which was considered to have demonstrated that timber-frame construction can meet the functional requirements of the Building regulations of England and Wales and the Building Standards of Scotland in terms of limiting internal fire spread and maintaining structural integrity.

The approximate temperatures close to the ceiling of the lounge area measured during the TF 2000 testing have been extracted from the project reports[78,79] and are plotted against time in Figure H1, together with the standard heating regime from AS 1530.4 and the parametric curve derived in accordance with the methods described in Section 10.6, which was then used to estimate the temperature of a standard element to compare the fire severity based on the peak element temperature. Dimensions were obtained from project reports with opening sizes scaled from drawings and photographs of the specimen.

The equivalent fire resistance exposure for the test calculated using the above approach was 58 minutes. The deterioration of parts of the structural elements was estimated to be consistent with an element exposed to the standard heating regime for approximately 66 minutes[78,79]. The parametric time temperature curve indicated an equivalent fire resistance period of 62 minutes if the enclosure had progressed to full burnout. The predicted exposures and performances using the methods of Section 10.6 were therefore within 10% of the measured/estimated performance from this experiment. The enclosure temperatures were trending downwards just prior to application of water, indicating that the fire may have been entering the decay phase, but no firm conclusions can be drawn with respect to total burnout.

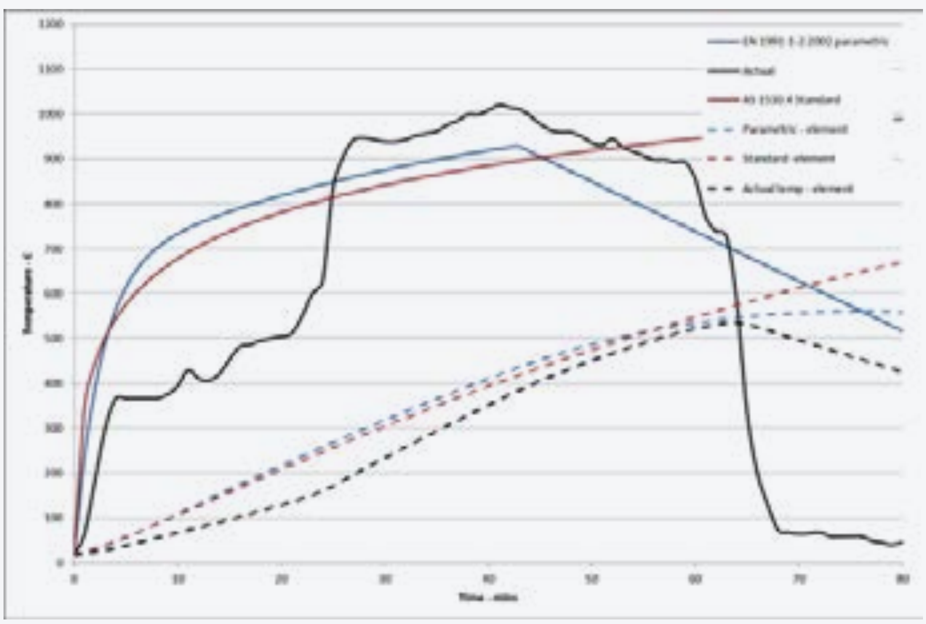


Figure H1: TF 2000 Analysis of fire severity.

Appendix I: Analysis of Fire Spread Via Concealed Spaces

I1 Frequency of Ignition in Concealed Spaces

From Section 10.2, the frequency of reported fires was estimated to be 1 x 10^{-3} fires/apartment/ year, of which 18% were estimated to be potential flashover fires.

The following fire start rates in concealed spaces were derived in Appendix F3, based on data from single dwellings for which the NCC requires fewer fire safety precautions than mid-rise buildings:

- 0.8% within a wall assembly
- 2.9% in the concealed space between a roof and ceiling
- 0.6% in the concealed space between a floor and ceiling.

The large difference in the rate of fire starts between floors and roof construction may in part be due to a fewer number of two-storey (or more) single dwellings and also the greater range of building services within roof spaces. These estimates are expected to be very conservative, since Class 1 buildings have fewer controls than medium-rise Class 2 and 3 buildings designed in accordance with the NCC 2016 fire-protected timber requirements; in particular, the proposed fire-protected timber elements require non-combustible linings to be applied to the timber, whereas combustible linings are permitted in Class 1 buildings.

It was therefore considered conservative to assume approximately 0.8% of fires initiate within cavities.

A detailed investigation into cavity fires was undertaken as part of the TF2000 project in the UK[82] that estimated that approximately 0.07% of fires are initiated in structural cavities, which is an order of magnitude smaller – implying the adopted value is very conservative.

Further discussion and background information on the findings of the TF2000 project are provided in Appendix H.

I2 Frequency of Fully Developed Fire Scenario with Spread to Cavity

This scenario was considered the most critical because of the higher frequency and the risk that a cavity fire will be coincident with a fully developed fire in a building.

A multi-tiered approach was therefore adopted to address this scenario, providing a robust fire safety strategy that is not solely reliant on any one element. The following measures prevent the fire spreading to the cavity in the first place:

- fire sprinklers installed in accordance with Specification E1.5 with an estimated reliability of 92%
- fire protection linings achieving incipient spread of fire ratings of 45 minutes
- requirements for service penetrations to meet the incipient spread of fire criteria and for cavity barriers to be fitted around windows and doors to maintain the integrity of the fire-protective linings.

Taking fire brigade intervention into account, the fire protection linings were estimated to be sufficient to prevent fire spread to the cavity in about 99% of scenarios, ignoring the impact of inadequate fire penetration seals and other defects.

If the probability of service penetration installations having major faults is taken as 0.11, the reliability of the fire protection linings in conjunction with timely fire brigade intervention with respect to preventing ignition will be taken as approximately 88%.

The probability of fire spread to the cavity from a potential flashover fire would therefore be (1-0.88) x (1-0.92) = .0096 (say 0.01). If the proportion of flashover fires is taken as 18%, then only about 0.18% of fires may spread to the cavity due to flashover fires.

The above measures substantially reduce the probability of spread to the cavity to less than the frequency of fires initiating within the cavity.

I3 Ignition Sources within Cavity

The TF 2000 analysis indicated that where the cavity construction material is the material first ignited or primarily responsible for fire growth and spread, the ignition mechanism is commonly attributable to the misuse of devices such as blow torches, paint strippers or other equipment generating similar levels of heat output or sparks. Therefore, in the majority of incidents, it is likely that the fire will be observed at or close to the time of ignition and the fire brigade alerted quickly.

Although much less likely, another ignition risk is from electrical faults and overheating. The frequency of these types of fire scenario is likely to reduce with the adoption of lower energy lighting and other services.

I4 Mitigation Measures for Fires within Cavities

The following additional mitigation measures are adopted in the NCC 2016 to mitigate the effects of scenarios where fire spreads to cavities or initiates in cavities:

- Any insulation in wall and floor/ceiling cavities must be non-combustible to ensure that if insulation is provided within the cavities it will tend to limit growth and fire spread and not introduce additional hazards.
- Cavity barriers at junctions with other fire-resistant elements of construction must be provided having FRLs of at least -/45/45 to prevent incipient fire spread to adjacent structural elements if a significant fire develops within the cavity.
- Larger floor cavities are required to have fire sprinklers fitted within the cavity in accordance with the requirements of NCC Specification E1.5 which will limit growth and fire spread within the protected areas.

I5 Performance of Cavity Barriers

Exposure during fire resistance test on partition with unprotected PVC pipe penetration

A fire resistance was undertaken on a 272-mm-thick twin-framed party wall system that included a 100 mm nominal size uPVC pipe penetration without fire protection. Horizontal and vertical cavity barriers comprising mineral fibre blanket were fitted between timber structural elements at the head and base and top of the wall system. From a review of the temperature data in the report, after about 10 minutes elevated temperatures above the ignition point of timber occurred in the cavity due to collapse/failure of the non-fire-stopped pipe. However, the impact was very localised, so the time for the mean cavity air temperature to reach 300°C was only reduced by 10 minutes, leading to a reduction in the structural adequacy under full load conditions from the expected 90 minutes to 72 minutes, at which point the load was removed and the test continued to 90 minutes. After 90 minutes of the test, the cavity temperatures were below 600°C and the fire protection linings were still in place.

It is therefore concluded that systems capable of achieving FRLs of -45/45, or comprising mineral wool strips placed under compression when installed with a minimum depth /thickness under compression of 45 mm or 45 mm thick timber, would retard fire spread to an appropriate extent.

UK study of the fire risks in Combustible Cavities – Fire Tests

Cavity barrier provisions were considered as part of a detailed analysis undertaken for the UK Department of Trade and Industry by Lavender, Bullock and Lennon[82].

An initial test was undertaken on a standard configuration that incorporated OSB sheathing, breather membrane and a vapour barrier in addition to the timber frame, with a small ignition source comprising six 100 mm x 20 mm x 15 mm sticks and 100ml of paraffin. This type of ignition could be considered to represent a typical ignition during maintenance/construction activities or a severe scenario resulting from ignition within a concealed space due to an electrical fault. An initial peak temperature of approximately 220°C occurred shortly after ignition. This was followed by a smouldering phase until, after approximately 3.5 hours, re-ignition occurred and a peak temperature of 280°C was reached before a rapid reduction in temperature.

A test method was developed to simulate a combustible cavity construction with severe fire exposure of the cavity to evaluate different cavity barriers. The fire comprised a single 18 kg timber crib of 50 mm x 50 mm sticks capable of burning for more than 60 minutes. A small amount of paraffin was used to facilitate ignition of the crib. The average temperature within the cavity below the cavity barriers was 600°C. This scenario appears comparable to the impact of a gross defect with the fire penetrating a large opening during the early stages of a fully developed fire. Four tests were reported and the results are summarised in Table I1.

Table I1:UK cavity fire simulation tests.

Test No	Description	Result
1	PVC wrapped mineral fibre cavity barrier	Prevented fire spread >60 minutes
2	Solid timber battens	Prevented fire spread >60 minutes
3	PVC wrapped mineral fibre cavity barriers including discontinuities to simulate poor workmanship	Ignition within the cavity of the top panel occurred. Temp >250°C 2 mins (unspecified location) Approximate temperatures measured 250 mm above cavity barrier (scaled from graph) 5 min after start of growth – 250°C 15min after start of growth – 300°C 60min after start of growth – 415°C
4	Proprietary intumescent honeycomb cavity barrier	Prevented fire spread >60 minutes

Systems 1 and 2 represented current UK Deemed-to-Satisfy requirements (38 mm timber and compressed mineral wool panels). The UK-approved documents require proprietary systems to achieve the equivalent of an FRL of -/30/15. These requirements are similar to the proposed Australian requirements, except that the minimum thickness of timber is 45 mm and proprietary systems are required to achieve an FRL of -/45/45, reflecting the higher FRLs specified for loadbearing elements in Australia.

Cavity fire incident after the TF2000 fully developed apartment fire test

The potential consequences of incipient spread of fire through cavities were demonstrated during the TF 2000 test series when fire spread through cavities after the initial fire test had been extinguished[81]. Steam was released from the hot structure after suppression of the apartment fire but, after approximately 2.5 hours, hot smoke was observed being released from around the living room window area and a call was made to the fire brigade. Approximately 5.5 hours later, the fire was declared to be extinguished. The long period of time for suppression to occur can be explained by the difficulties identifying the seat of the fire and subsequently gaining access to apply water. Subsequently deficiencies were identified with the installations of cavity barriers. This event provides very useful data on which to quantify the potential consequences from fires spreading to concealed cavities with poorly installed cavity barriers.

The cavity fire occurred in an external wall, which comprised a timber frame with two layers of plasterboard lining the internal face; OSB sheathing and breather membrane was attached to the opposite face of the frame. There was a cavity separating the timber frame from the external brick veneer of the wall. This arrangement represents a severe configuration, since OSB sheathing is only required if walls require bracing. At the base of the gable wall where most of the vertical fire spread took place, the base of the cavity was open over a length of 4.8m due to a previous structural test, which may have had a significant effect on vertical flame spread due to the additional ventilation.

It is therefore considered reasonable to use data from this event to estimate the consequences of a serious event where the presence of a serious fire was overlooked for a considerable period and fire spread to and through concealed cavities. The key events on the timeline are summarised below based on a review of the reports[79,80,82,83]. These vary slightly from some reported times, due to difficulties cross-referencing different time scales.

- t=0mins: Initial fire in apartment ignited
- t=64min: Fire suppression in living area
- t=150min: Temperature rise in cavity close to living room window
- t=221min: Fire Brigade called – temperature data indicates rapid fire growth within cavity of the flat above – flaming observed from a timber window frame at approximately this stage
- t=261 min: Cavity temperature in flat above flat of fire origin peaks above 700°C – temperature within flat peaks below 45°C
- t=262min: Fire Brigade withdraw from building because cracking of brick veneer observed
- t=266min: Eaves protection removed to access cavity – suppression activity occurs
- t=275min: Additional window frames removed to provide access
- t=549min: Fire brigade confirm fire under control.

The investigations concluded that the fire had spread from the wall ceiling interface in the corner of the living area through timber studs and that the horizontal cavity barriers had not been installed effectively, allowing the fire spread to occur. The fire spread from the fire floor through the floor above, effectively removing the loadbearing capacity of the external walls at these locations.

After this severe incident with spread occurring without effective intervention for several hours, it is noteworthy that the temperature rise within the flat above was of the order of 20°C and damage was restricted to the cavity, so the impact on life safety would be expected to be minimal, provided there was no disproportionate collapse.

The NCC performance requirement BP1.1 requires a structure "to be designed to sustain local damage, with the structural system as a whole remaining stable and not being damaged to an extent disproportionate to the original local damage" among other things. To facilitate this, a Guide has been developed and the author of the guide has provided the comment included as Appendix J on the likely structural consequences of the above event. The level of damage was considered representative of severe scenarios where: ignition occurs within a cavity; the fire grows without being constrained by lack of oxygen, non-combustible insulation or fire sprinklers within the cavity; and the cavity barriers fail, allowing spread to an adjoining element.

I6 Summary of Conclusions drawn from UK Study into Combustible Cavities

Cavity Barrier Provisions were considered as part of a detailed analysis of the fire risks in combustible cavities undertaken for the Department of Trade and Industry UK by Lavender et al.[82] The major conclusions drawn from the project were:

- Statistics indicate that, as a percentage of fires attended by the Fire Brigade in any year, cavity fire events (where the cavity construction is identified as the first material ignited or the material mostly responsible for fire development) represent a very small fraction of the total. Approximately 1 in every 1400 fires or 0.07% of these fires.
- Statistics indicate no fatalities and very few injuries resulting from cavity fires.
- A review of anecdotal reports, fire investigation records and fire statistics indicates that there is no evidence at present to suggest that a rise in the number of timber-frame residential buildings will result in an increase in the number of fire casualties. This assumes that buildings are constructed in accordance with the guidance of various published statutory instruments in support of Building Regulations.
- Fire reports, investigation records and statistics indicate where the cavity construction is the material first ignited or primarily responsible for fire growth and spread. Where this is the case the ignition mechanism is commonly attributable to the misuse of devices such as glow lamps, paint strippers or other equipment generating similar levels of heat output or sparks. This misuse of equipment needs to be addressed by relevant bodies in the provision of adequate guidance.
- When properly installed, current commonly specified cavity barrier types meet the functional requirements of Building Regulations. The workmanship involved with the installation of cavity barriers has the greatest implication on the cavity barrier meeting the functional objectives of the Building Regulations.
- Irrespective of construction type and ignition scenario, cavity fires may be difficult to locate and extinguish.
- A type of timber-frame cavity construction that utilises non-combustible materials or materials of limited combustibility helps to remove/reduce the risk of significant fire growth and spread within a concealed cavity. However, it should be noted that this form of construction has its own inherent problems. Ease of construction can be problematic, including excessive damage during construction. Exposure during inclement weather throughout erection can affect the material properties of the construction if left unprotected.
- Anecdotal reports and fire investigation records indicate that the use of combustible insulation materials in external wall cavities where both leaves are of masonry construction may give rise to a situation where fire growth and spread within the cavity is significant and where the fire service could encounter significant difficulty in dealing with the fire.
- Fire Brigades possess tools to locate the seat of a cavity fire within a short space of time after arriving at the scene. However, information/ training material on the correct method of searching a building for the fire source located within a cavity needs to be disseminated for all construction types.

- The project has highlighted that there are a number of 'toolkit' measures that can be employed by Design/Project Teams to ensure that the functional objectives of Building Regulation B3 are met and that the risk of fire in cavities is further reduced. These are as follows:
  - The option of designing the cavity so that it is lined with non-combustible materials or materials of limited combustibility.
  - Use of tested and approved proprietary cavity barriers fitted in accordance with manufacturers recommendations and used within the limits of the stated field of application for the product.
  - Clarification of responsibility within the construction Project Team in respect of workmanship issues relating to the installation of fire protection measures such as cavity barriers.
  - Instruction of contractors by approved bodies and appropriate supervision at key stages to ensure that cavity barriers are being installed correctly and the installation is not compromised by follow-on trades.

I7 Quantification of Risk from Cavity Fires

I7.1 Fires Spreading To Cavities of Fire-protected Timber Elements

To quantify the risk of fire spread through cavities it is necessary to establish the probability and consequences for the potential scenarios.

Fire spread to the cavity could result from:

- ignition of the timber structural elements due to heat penetration through the fire protection linings, in the event of a severe fire coinciding with slow fire brigade intervention
- inadequately fire-protected service penetrations
- gross defects in the fire protection linings leading to premature exposure of the structural frame.

In all the above scenarios, if the mitigation measures required by the NCC Deemed-to-Satisfy Provisions are effective, fire spread via the cavity will not occur and the damage will be restricted to a single element. The consequences from such events were inherently taken into account in the Monte Carlo analysis of apartment fires.

In some instances, the provision of non-combustible insulation and sprinkler coverage in larger cavities will be sufficient to prevent fire spread without reliance on cavity barriers but, for the purposes of this analysis, it will be assumed that fire spread will occur if the cavity barrier installation has serious defects. The probability of serious defects occurring in a cavity barrier will be based on the estimates for service penetrations (i.e. 0.11).

The percentage of fires spreading to cavities based on the preceding analysis is approximately 0.18% of fires and hence the percentage of fires spreading through cavities to adjacent structural elements would be 0.18 x 0.11 ≈ 0.02%. This equates to a frequency of 2 x10^{-7}/apartment /annum or for the subject building with 42 apartments 8.4 x 10^{-6} /annum.

The outcomes or consequences of this scenario are expected to be broadly similar to the event after the TF2000 fully developed fire test (described in Section I5) if there is no effective fire brigade intervention for several hours.

The inherent fire resistance of a loadbearing wall with gross defects has been estimated to be approximately 22 minutes. Based on the test results described above, the cavity barrier would be exposed to temperatures in the range of 400 to 600°C due to shielding of residual boards and, if there are faults with the cavity barrier at the same time, cavity temperatures are unlikely to exceed 450°C locally to the fault and would reduce considerably over the area of the partition. It is therefore considered very unlikely that the ring beam and partition in the apartment above would fail prior to fire brigade intervention. A 10% probability of significant damage to the above partition and the ring beam above will be assumed.

Under these circumstances, sufficient time would be expected to be provided for evacuation of occupants most at risk and disproportionate collapse is still unlikely to occur.

Based on this discussion, it is estimated that the frequency of fire spreading to adjacent compartments via cavities and breaking out or causing a major structural collapse is of the order of 8.4 x10^{-7} /annum (i.e. approx 1 x 10^{-6} fires per annum). If this occurs, the risk to life is expected to be low since the onset of untenable conditions and collapse would be slow; providing time for search and rescue and evacuation. If a major structural failure was to occur, the failure would be expected to be localised if the building is designed to resist disproportionate collapse and – considering the low probability of the event and number of primary fire safety systems required to fail for this outcome to eventuate – the losses were considered to be consistent with the probability of occurrence.

I7.2 Fires Initiating in Cavities of Fire-protected Timber

Based on the results from the fire tests performed in the UK with relatively small ignition sources consistent with maintenance activities, the probability of fire spread within the cavity is small and the rate of fire growth is also expected to be slower than the fire scenarios considered in I7.1. It is therefore considered likely that most fires occurring during maintenance activities would be suppressed either by occupants or the trades responsible, or fire fighters. Assuming approximately 95% of the small fires self-extinguish or are suppressed by the occupants or fire brigades before threatening structural damage, the frequency of fires growing to such an extent that significant structural damage could occur would be $1 \times 10^{-3} \times 0.8/100 \times 0.05 \times 46$ fires/annum (approximately 2×10^{-5} fires per annum).

Since these fires would be initially slow growing, the fires would be expected to be suppressed prior to causing significant damage to the apartment above, or the occupants would evacuate. Therefore, the risk to occupants would be relatively low because the fire would be contained within the cavity and spread within the cavities should be retarded by cavity barriers.

J

Appendix J: Comment on Structural Design Implications

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12th January 2015

Paul England
EFT Consult

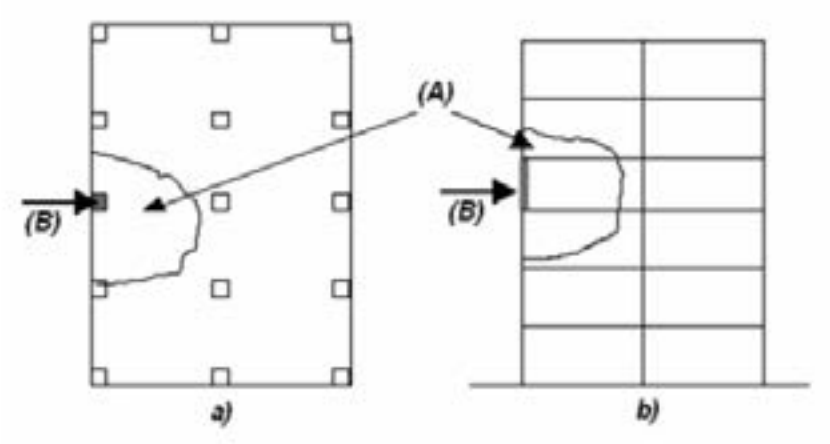
Disproportionate Collapse: Fire in Cavities

Paul,

Further to your email and our subsequent telephone conference with Boris Iskra on 19th December 2014 we provide the following letter as a summary of our approach to the disproportionate collapse of a typical stick frame building in the event of fire damage to a cavity wall system. This summary is based on the guide to structural robustness and disproportionate collapse which is currently being developed by the FWPA and AECOM.

Summary of approach to the robustness

Fundamental to the design guide is the concept of disproportionate collapse which is to say that a building should be constructed so that in the event of an accident the building will not suffer collapse to an extent disproportionate to the cause. The guide is recommending to adopt the Eurocode definition of what is considered disproportionate as an area of local damage upon notional removal of a loadbearing element. The Eurocode requires that the area likely to collapse be less than 100m² or 15% of the floor area (whichever is smaller), over no more than two adjacent storeys.



Key

(A) Local damage not exceeding 15 % of floor area in each of two adjacent storeys
(B) Notional column to be removed
a) Plan b) Section

Figure 1: Eurocode definition of disproportionate collapse area.

Fire in Cavities

The following diagrams describe the cavity fire conditions assessed. Four scenarios are presented with increasing areas of fire damage and the likely structural response is described.

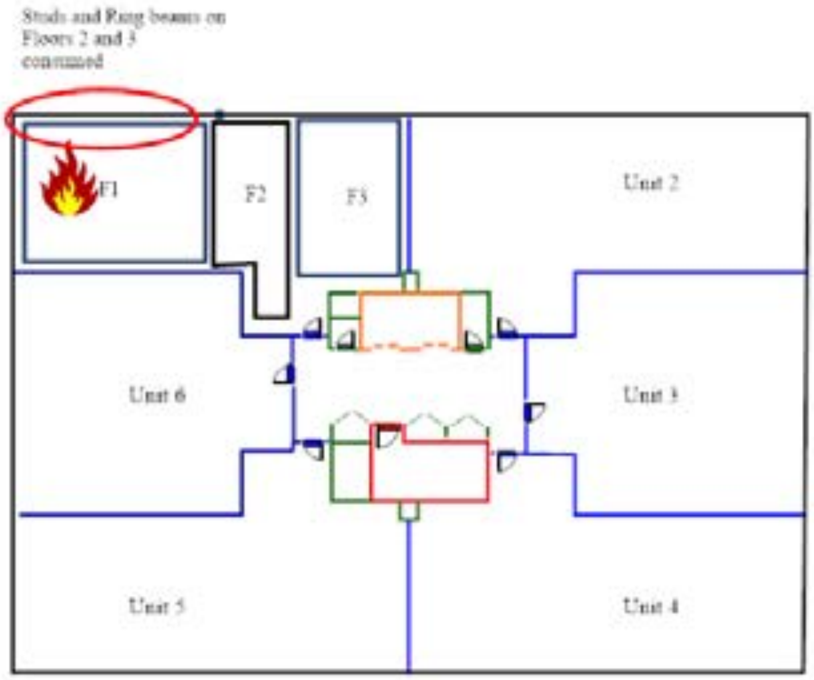


Figure 2: Plan of fire compartments

Figure 3: Sections through typical timber apartment building

The following table assumes the external wall is a loadbearing wall (fire damage to walls in the non-loadbearing direction is unlikely to cause disproportionate collapse).

Scenario	Description	Likely structural response (assuming Robust Design procedures adhered to)	Considered disproportionate?
1	Fire in lounge area of 2nd floor apartment timber stud wall frame lost but ring beam above wall frame remains substantially intact.	Loadbearing wall at level 2 ineffective but ring beam at level 3 spans over gap and distributes wall loads from above into adjacent structure. Floors remain intact	No. No floor area likely to be lost
2	Fire in lounge area of 2nd floor apartment timber stud wall frame lost and ring beam above wall frame also lost on that level.	Loadbearing walls ineffective at levels 2 and 3, ring beam at level 3 ineffective. Potential local collapse of 3rd floor. Ring beam at 4th floor spans over gap and prevents collapse of further floors above. Debris load on the 2nd floor is unlikely to exceed the design capacity of the floor and should remain intact.	No. Some area of floor lost (approx. 20m²) but not considered disproportionate to the cause
3	Fire in lounge area of 2nd floor apartment; timber stud wall frame and ring beam lost on 2nd floor and wall frame on 3rd floor lost.	As scenario 2	As scenario 2

AECOM

4	Fire in lounge area of 2nd floor apartment; timber stud wall frame and ring beam lost on 2nd floor and timber stud wall frame and ring beam on 3rd floor lost.	Loadbearing walls and ring beams ineffective at both levels 2 and 3. Likely local collapse at both 3rd and 4th floors. Ring beam at 5th floor spans over gap and prevents collapse of further floors above.	No. Some area of floor lost (approx. 40m²) through the loss of the loadbearing walls. Debris load on the 2nd floor of two collapsed floors to be included for in the design of the floors to prevent further collapse.

Figure 4: Table of fire in cavity scenarios (corner apartment)

Scenario 4 is the worst design case. Two floors are likely to collapse with the removal of the loadbearing walls over two levels but the floors above should be expected to remain intact. The collapse of the 3rd and 4th floors can potentially lead to a large debris load on the 2nd floor and this should be accounted for in the design and will most likely be the governing loadcase for the floor design. The guide to robustness and disproportionate collapse will recommend the inclusion of "strong floors" which will be designed to support the additional load from debris from two floors if this scenario is considered likely.

In the case of the fire in an internal wall between apartments the above table still applies. Areas of floor lost will be increased but are still likely to be less than 15% of the total floor area. With the loss of an internal loadbearing wall there is also the possibility that other alternate loadpaths are present through hanging of floors or other continuous spanning members and this will only serve to increase the robustness of the structure.

Should you wish to discuss any of these matter further then please don't hesitate to contact me.

Sincerely,

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cc Boris Iskra, FWPA

K

Appendix K: Class 5 Office Analysis

K1 Relevant NCC Definitions

Definition of Class 2 Buildings

Class 2: a building containing 2 or more sole-occupancy units each being a separate dwelling

Definition of Class 3 Buildings

Class 3: a residential building, other than a building of Class 1 or 2, which is a common place of long term or transient living for a number of unrelated persons, including –

(a) a boarding house, guest house, hostel, lodging house or backpackers accommodation; or

(b) a residential part of a hotel or motel; or

(c) a residential part of a school; or

(d) accommodation for the aged, children or people with disabilities; or

(e) a residential part of a health-care building which accommodates members of staff; or

(f) a residential part of a detention centre.

Definition of Class 5 Buildings

Class 5: an office building used for professional or commercial purposes excluding buildings of Class 6, 7, 8 or 9

Definition of Sole-occupancy unit (SOU)

Sole-occupancy unit means a room or other part of a building for occupation by one or joint owner, lessee, tenant, or other occupier to the exclusion of any other owner, lessee, tenant, or other occupier and includes –

(a) a dwelling; or

(b) a room or suite of rooms in a Class 3 building which includes sleeping facilities; or

(c) a room or suite of associated rooms in a Class 5, 6, 7, 8 or 9 building; or

(d) a room or suite of associated rooms in a Class 9c aged care building, which includes sleeping facilities and any area for the exclusive use of a resident.

K2 Comparison of Critical Parameters for Class 2, 3 and 5 Buildings

Review of Performance Requirements

See Appendix D for a review of relevant performance requirements.

Function and Use of the Building

The differences in the function and use of Class 2 and 3 buildings compared to Class 5 buildings have been considered in the following sections.

Fire load

Table K1 compares the design loads specified in typical codes and verification methods with the outcomes of a literature review undertaken by Ocran. It is noteworthy that the fire load for offices stated in Eurocode 1 is approximately 54% of that for dwellings, but in the NZ verification method the design value for offices is 200% of the design value for dwellings. Ocran's review of surveys of office fire loads found large variations between studies (mean values between 348-1321MJ/m^2; however, a recent survey reported in 2012 indicated a mean fire load of 557 MJ/m^2 – possibly because of the trend towards open-plan offices and less dependence on paper records and hard copy publications.

Table K1: Comparison of fire loads.

Survey/Design Code	Mean Fire Load Density or Design Fire Load Density MJ/m2		
	Dwelling (incl. Class 2)	Hotel (Class 3)	Office (Class 5)
Eurocode1 Parts 1 and 2[22]	780	310	420
NZ verification Method C/VM2[24]	400	400	800
Ocran[23] (Range from lit review and studies)	370-550		348-1321
2012 study referenced by Ocran for offices			557

The analyses for Class 2 and 3 buildings assumed a mean value for the fire load of 500MJ/m^2 with a standard deviations of 150MJ/m^2.

A sensitivity study was undertaken as part of the Class 2 and 3 analyses for a range of mean fire loads from 300 to 780 MJ/m^2 (as shown in Table K2) and the relative results were not found to be sensitive to these variations. Therefore, subject to other factors being considered, the fully developed fire modelling obtained from the Class 2 and 3 building analyses can be considered generally applicable to Class 5 buildings.

Table K2: Fire loads used in report EFT2858NCCSupplement 1-3 for sensitivity analysis.

Fire Loads	Fire Load MJ/m^2	Standard Deviation MJ/m^2	95 percentile MJ/m^2	Min MJ/m^2	Max MJ/m^2
Low sensitivity	300	90	448	100	unlimited
Design Value adopted for Class 2 and 3 buildings	500	150	747	200	unlimited
High sensitivity	780	115	970	200	unlimited

Potential fire intensity

Class 5 buildings extend the range of room geometries beyond that typical of Class 2 and 3 buildings, with potential for large open-plan offices and large length-to-width ratios for some office configurations, and there could be corresponding changes to ventilation conditions. However, significant numbers of offices will have configurations similar to those considered for Class 2 and 3 buildings. As noted above, the fire load will be similar to the range of values considered in the sensitivity analysis for Class 2 and 3 buildings. Ocran[23] identified that surveys indicated the majority of the fire load in office buildings comprised cellulosic type materials that would be expected to release volatiles at a slower rate to plastic materials, tending to extend the fire duration but reduce the peak burning intensity if a fire is not ventilation controlled.

Bennetts et al.[83] described a number of full-scale fire experiments with typical office furnishings and contents. Table K3 summarises the results from tests performed without sprinkler protection and with unprotected steel beams mounted below concrete slabs and shielded by non-fire-resistant suspended ceilings – typical of those used within office buildings. The exposure of the steel beams is expressed as an equivalent fire-resistant period, calculated in accordance with empirical correlations for unprotected steel included in Section 12 of AS 4100. An effective heat of combustion of 18 MJ/kg was used to convert the fuel load from mass to energy per unit floor area.

Table K3: Fire intensity/exposure data from office fire test experiments.

Element	Fire Load kg/m²	Fire Load MJ/m²	Max enclosure temp. °C	Ceiling tiles	Beam ESA/M m2/T	Max beam temp. °C	Calc. equiv. FRL min
Single office 1989 (4 m x 4 m)	45	810	1,100	Mineral fibre	29.3	390	10.2
140 Williams St Test 4 (12 m x 12 m area)	50	900	1,200	Plaster	26.6	530	15.1
8.35 x 3.37 enclosure	-	-	1,163	Plaster	26.6	400	11.1
Timber crib fire load (12 m x 12 m)	46	828	1,000	Plaster & mineral fibre	19.9	530	18

From Table K3 it can be observed that peak enclosure temperatures range from 1,000 to 1,200°C, which is within the range of peak enclosure temperatures previously analysed for Class 2 and 3 buildings. The exposure of the steel beams shielded by non-fire-resistant ceilings ranged from 10 to 18 minutes. For the Class 2 and 3 building analysis, non-fire-resistant ceilings were assumed to provide a contribution of approximately 10 minutes to the FRL. On this basis, the equivalent FRL exposure period for the tests summarised in Table 4.3 would have been between 20 and 28 minutes. This is at the lower end of the range of fire scenarios considered during the analysis of Class 2 and 3 buildings.

It is therefore reasonable to conclude that the potential fire intensity would not be greater than the previously analysed Class 2 and 3 buildings.

Fire hazard

The fire hazard associated with Class 5 buildings is substantially less than that associated with Class 2 and 3 buildings, with the frequency of fatalities and injuries from office fires being so low in Australia it is difficult to draw firm conclusions other than the hazard is very much lower than that associated with dwellings.

Bennetts et al.[83] considered the much larger US data base over the period 1983 to 1991 to characterise the fire hazard associated with office buildings but indicated that it showed similar trends to Australian data.

Table K4 shows data relating to the number of fires and fatalities from the Bennetts et al. report together with the calculated number of fatalities per 100,000 fires. Using probability of fire occurrence and growth (per m²/year) data derived by Fontana et al.[84] based on a survey of 40,000 fires in Switzerland, the fatality rate /m² values for residential buildings has been compared to that for offices.

Table K4: Comparison of fire hazard in residential buildings compared to office buildings.

Parameter	1 and 2 Family Dwellings	Apartments	Offices
Number of fires	1,519,848	375,551	27,679
Number of civilian fatalities	13,036	2,844	31
Civilian fatalities/1,000 fires	8.6	7.6	1.1
Probability of fire occurrence x 10-6/m²/year	33.3	33.3	10.6
Comparative risk to life /m² of floor area	24.1	21.2	1.0

Therefore, the risk to life/m² of floor area due to fire in residential buildings is expected to be of the order of 20 times higher than that of office buildings.

Recent analyses from the US undertaken by Campbell[85] for the period 2007–2011 are consistent with the above statistics indicating an average of 3,340 fires in office properties per year, 44 civilian injuries and 4 civilian fatalities.

Both Campbell and Bennetts et al. identified that fewer than one-third of fires occur outside working hours, but these fires accounted for about two-thirds of direct property damage. Bennetts et al. also identified that fires outside working hours also accounted for about two-thirds of civilian fatalities.

Other findings by Campbell were:

- 29% of fires were caused by cooking equipment but only accounted for 6% of property damage.
- 10% of fires were deliberately lit but accounted for 20% of property damage.
- Electrical distribution and lighting equipment was the second largest cause of fires (12%) and caused 15% of the property damage.
- 12% of fires in office buildings started in office areas and caused 24% of the property losses.
- 2% of office fires occurred in concealed spaces including ceiling and roof spaces but accounted for 13% of direct property damage.
- 80% of fires were confined to the room of fire origin
- Sprinklers were present in approximately 33% of fires.
- Wet pipe sprinklers operated effectively 88% of the time in fires large enough to activate the equipment.
- Deaths were 62% lower in properties with automatic wet pipe sprinkler systems (due to the small sample size this result will be sensitive to single events).
- Property losses per fire were 46% less when wet fire sprinklers were present.

Similar trends were identified by Bennetts et al. who also identified the following:

- Flame spread was limited to the area or object of fire origin 70% of the time during normal working hours compared to 48% during non-working hours.
- Early intervention of occupants was inferred by the reduced activation rates for both sprinklers and detectors during normal working hours.
- 50% of victims appeared to be intimately involved with the fire start.
- Liquid fuels were involved in 42% of fires in which fatalities occurred (mostly incendiary fires).

Based on the above discussion, it can be concluded that the overall fire hazard is substantially less in Class 5 buildings compared to Class 2 and 3 buildings, but there are differences in the nature of the fire hazard associated with office buildings that will be taken into account when applying the findings from Class 2 and 3 buildings to Class 5 buildings.

Height of the building/number of storeys

There were no changes to the height of building/number of storeys adopted for the Class 2 and 3 studies.

Proximity to other property

There were no changes to the proximity to other buildings adopted for the Class 2 and 3 studies.

Active fire safety systems

The main variations between the active fire safety systems between the Class 5 building compared to the Class 2 and 3 buildings previously analysed were:

- Internal hose reels were provided in Class 5 buildings in addition to fire extinguishers.
- Smoke hazard management provisions comprised an automatic fire detection system for the control building and an automatic sprinkler system for the subject timber buildings (without supplementary detection systems).

Size of fire compartment

Individual SOUs in Class 5 buildings cannot be considered to comprise fire compartments, as is generally the case with Class 2 and 3 buildings, and in many instances the entire floor of a building will make up a fire compartment. For the subject building with a single stair, the floor area of a typical fire compartment may therefore increase from 100m^2 for Class 2 and 3 buildings to approximately 600m^2. Larger compartment areas may occur in buildings with more than one fire-isolated stair but it was considered that a single stair represents a worse case with respect to life safety because of the reliance on a single evacuation path. The potential impact on fire severity was discussed above but larger compartment sizes will also impact on fire brigade intervention, occupant response and potential protection of occupants not directly involved in the fire.

Fire brigade intervention

During the periods of occupation of office (Class 5) buildings, the fire brigade are likely to be alerted substantially before flashover by the occupants, yielding a quicker response than assumed in the Class 2 analysis. Even though the control building has a fire detection system, the alarm is not monitored, and so the fire brigade response is dependent upon notification by the occupants or public. For the timber buildings, the fire brigade will receive an automatic call from a monitoring system if the fire is large enough to activate an operational sprinkler system, and the fire is likely to have been supressed or controlled by the sprinkler system before the fire brigade respond.

Outside working hours, there may be few or no occupants in a Class 5 building, and there could be a significant delay before the fire brigade are alerted for the control building without monitored alarms. This could lead to the fire brigade having to respond to a larger fire than for typical Class 2 and 3 buildings, although the numbers of occupants to evacuate will be substantially fewer. For the timber buildings, the sprinkler system will alert the fire brigade and control or suppress the fire, if it operates successfully. This provides similar conditions to those experienced with Class 2 and 3 buildings, except for sprinkler failure scenarios, where the conditions would be similar to the control building and the fire brigades may have to face a large fire.

Other elements supported

There are no changes to the structure or requirements for protection against disproportionate collapse and methods of analysis or proximity to other buildings adopted for the Class 2 and 3 studies.

Evacuation time/travel distance

The Deemed-to-Satisfy maximum distance from any point on the floor to the fire-isolated stair for the Class 5 subject building is 20 m. A different approach is adopted for Class 2 and 3 buildings by specifying the travel distance from the door of an SOU to the fire-isolated stair and a maximum distance of 6 m is specified. If a typical apartment layout is considered, the maximum travel distance from a point on the floor of an apartment to the fire-isolated stair would be comparable to the 20 m specified for a Class 5 building. However, evacuation times for occupants of a Class 5 building are likely to be less than a comparable Class 2 and 3 building, because occupants are likely to be awake and alert in Class 5 buildings and the reduced compartmentation will improve awareness of the rest of the floor in many instances.

Occupant mobility, number and characteristics

The occupant characteristics of Class 2 and 5 buildings can be considered to be broadly representative of the Australian community, with a diverse range of capabilities. Similar responses would be expected, except that occupants in Class 5 buildings would be expected to be alert, less likely to be under the influence of alcohol and drugs and more likely to assist others to evacuate and have undergone emergency evacuation training.

The analysis of Class 3 buildings considered greater proportions of occupants requiring assistance of fire brigade to evacuate.

Table D1.13 of the NCC[86] specifies the area per person based on type of use for certain occupancies. For Class 5 buildings, an occupant density of 10m^2/person is specified. The evacuation time would therefore be expected to be comparable to the values adopted for the Class 2 and 3 analyses.

Building fire safety system

The Deemed-to-Satisfy Provisions vary between Class 5 and Classes 2 and 3 to reflect the different nature of the occupancies and, in particular, higher hazard (risk to occupants in class 2 and 3 buildings).

K3 Generic Office Building Characterisation

K3.1 Building Layout and Fire Protection Details

The same general building layout as that adopted for the Class 2 building analysis was assumed. General layout details are shown in Figures K1 through to K3.

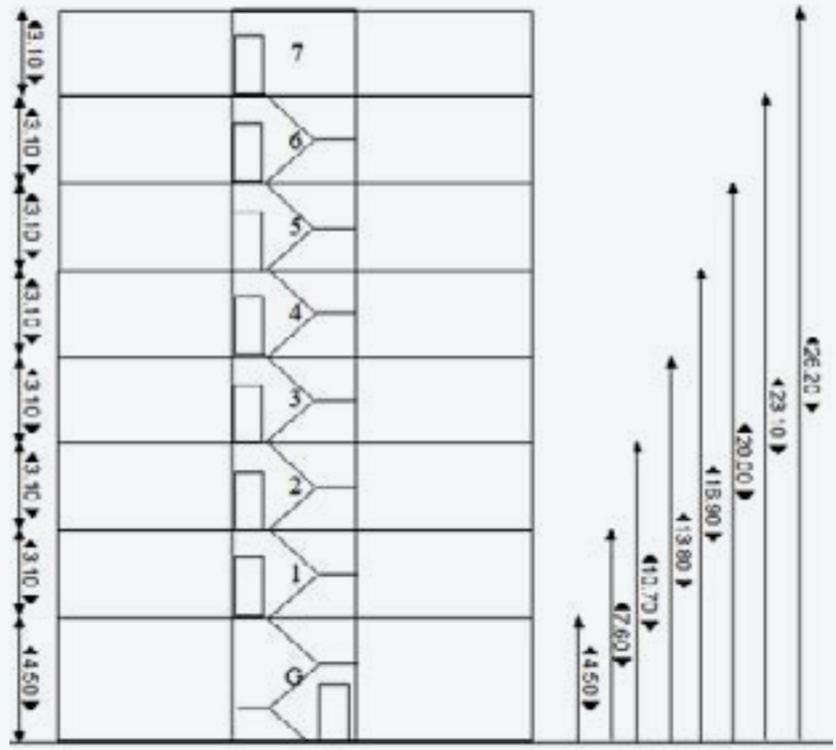


Figure K1: Vertical section through generic Class 5 building.

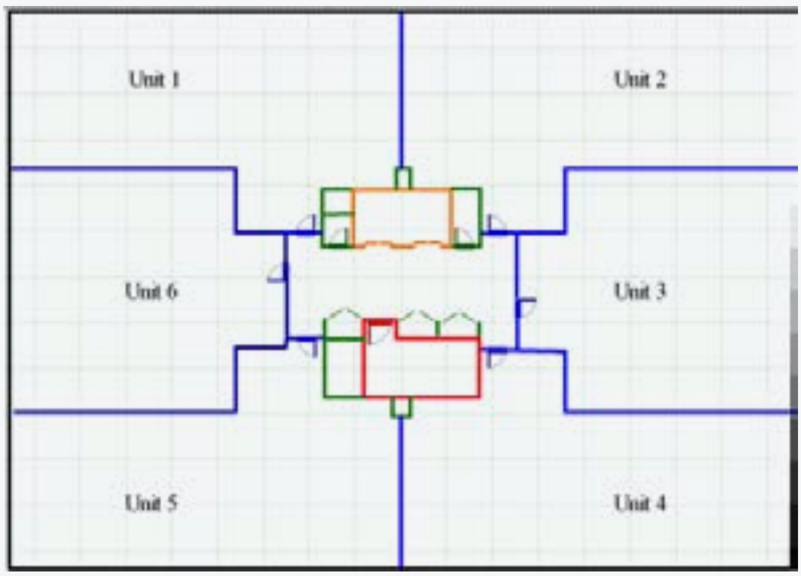


Figure K2: Horizontal section through typical upper floor of generic Class 2/3 or 5 building.

Figure K3 also shows a schematic layout of the ground floor with a typical fire indicator panel (FIP) location, fire stair access/egress, lift location and external fire brigade access.

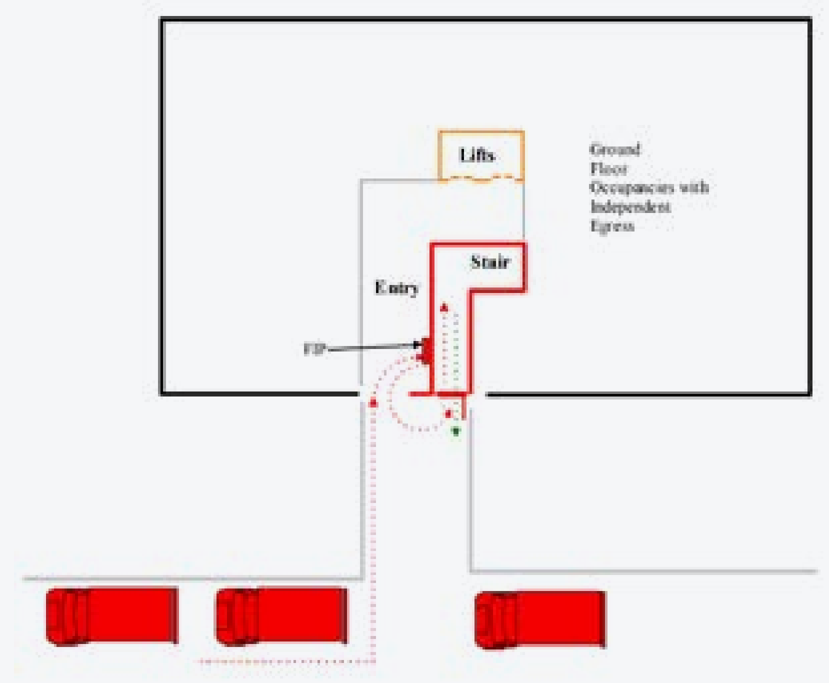


Figure K3: Ground floor plan of generic building.

Passive fire protection systems required by the NCC Deemed-to-Satisfy Provisions for the generic building are summarised in Table K5.

Table K5: Passive fire protection systems.

System	Deemed-to-Satisfy Provisions for control Class 5 building	Additional/alternative measures for timber construction
Fire resistant construction	Refer Table K6	No difference
Concrete and masonry construction	Load bearing internal walls (including shafts and fire walls)	Fire-protected timber
Non-combustible construction	External Walls Common Walls Flooring and floor framing to lift pits Non-loadbearing walls required to be fire-resisting Non-loadbearing shafts that do not discharge hot products of combustion Miscellaneous applications	Fire-protected timber
Fire hazard properties	Full compliance with Specification C1.10	No difference
Separation distances and openings in external walls	Full compliance with Deemed-to-Satisfy Provisions and non-combustible construction	Fire-protected timber in lieu of non-combustible construction

A steel-frame building has been selected for the control building since it is considered to most closely resemble the timber mid-rise buildings being considered in this report. Table K6 summarises the key elements of construction for the control and subject buildings.

Table K6: Passive systems FRLs for comparative analysis between control and timber buildings.

Element	Control building	Lightweight timber frame (Subject building 1)	Massive timber (Subject building 2)
Floor/ceiling assemblies FRL 120/120/120	Concrete slab supported on steel beams. Steel beams protected by sprayed-vermiculite to provide required FRL	Fire-protected timber floor comprising either solid joists or engineered timber beams spanning between timber-framed walls. Fire-grade plasterboard facings , 3 x 16 mm and timber/mineral fibre cavity barriers (-/45/45) used to protect timber	Fire-protected cross-laminated timber horizontal panels spanning between CLT walls Fire-grade plasterboard facings, 1 x 16 mm minimum used to protect timber
False non-fire rated standard plasterboard ceiling to allow service runs above for all buildings			
Columns/ loadbearing walls 120/120/120	Steel columns protected by sprayed vermiculite and clad with non- fire-grade plasterboard	Fire-protected timber-frame loadbearing walls. Fire-grade plasterboard facings, 2 x 16 mm and timber/ mineral fibre cavity barriers (-/45/45) used to protect timber	Fire-protected cross-laminated timber vertical panels Fire-grade plasterboard facings 1 x 16 mm
Non-loadbearing walls	Lightweight steel frame protected by 16 mm fire-grade plasterboard (-/120/120 FRL)	Lightweight timber frame protected by 2 x 16 mm fire-grade plasterboard and timber/ mineral fibre cavity barriers	Fire-protected cross-laminated timber vertical panels Fire-grade plasterboard facings 1 x 16 mm minimum
Lift and stair shafts	Structural steel framework protected by vermiculite non- loadbearing plasterboard shaft wall (-/120/120)	Fire-protected timber-frame loadbearing walls. Fire-grade plasterboard facings, 2 x 16 mm and timber/ mineral fibre cavity barriers (-/45/45) used to protect timber	Fire-protected cross-laminated timber vertical panels Fire-grade plasterboard facings 1 x 16 mm on outer face of shaft and 1 x 13 mm on inner faces, minimum
Service shafts -/90/90	Solid fire-grade plasterboard (multi-layer system)	Solid fire-grade plasterboard (multi-layer system) or fire-grade plasterboard facings, 2 x 13 mm and timber/mineral fibre cavity barriers (-/45/45) used to protect timber if integrated into apartment wall	Solid fire-grade plasterboard (multi-layer system) or cross-laminated timber protected by a minimum of 16 mm fire-grade plasterboard
External wall less than 1.5 m from fire source feature **FRLs 120/120/120 and -/120/120**	Structural steel protected by vermiculite lightweight steel studs protected by 2 x 13 mm fire-grade plasterboard	Lightweight timber frame protected by 2 x 16 mm fire-grade plasterboard and timber/ mineral fibre cavity barriers	Fire-protected cross-laminated timber vertical panels Fire-grade plasterboard facings 1 x 16 mm
External wall 1.5 m to less than 3 m from fire source feature. FRLs 120/90/90 and -/90/90	Structural steel protected by vermiculite lightweight steel studs protected by 2 x 13 mm fire-grade plasterboard	Lightweight timber frame protected by 2 x 16 mm fire-grade plasterboard and timber/ mineral fibre cavity barriers	Fire-protected cross-laminated timber vertical panels Fire-grade plasterboard facings 1 x 16 mm
External wall 3 m or more from fire source feature. FRLs 120/60/30 and -/-/-	Structural steel protected by vermiculite lightweight steel studs protected by 2 x 13 mm fire-grade plasterboard	Lightweight timber frame protected by 2 x 16 mm fire-grade plasterboard and timber/ mineral fibre cavity barriers	Fire-protected cross-laminated timber vertical panels Fire-grade plasterboard facings 1 x 16 mm
Fire doors -/60/30 modern prototypes with intumescent strips			

Table K7 summarises the active requirements for the generic Class 5 building.

Table K7: Active fire protection systems.

System	Deemed-to-Satisfy Provisions for control Class 5 building	Additional/alternative measures for timber construction
E1.3 **Fire hydrants**	Internal fire hydrants in accordance with AS 2419.1 provided for each storey	No difference
E1.4 Fire hose reels	Required for a Class 5 building (Not required in Class 2)	No difference
E1.5 Sprinklers	Not provided	System provided in accordance with Spec E1.5 (AS 2118.1)
E1.6 Portable fire extinguishers	Provided in accordance with Table E1.6 and AS 2444	No difference
E1.8 Fire control centre	Not required – building less than 25 m effective height	No difference
E2.2 Smoke hazard management **(independent exit from parts of other classes therefore no stair pressurisation required)**	Building-wide fire detection/alarm system in accordance with Spec. 2.2a.- Activation of any detector will raise alarm throughout the building	Sprinkler system provided throughout Activation of any head will raise alarm throughout the building
E2.2 System monitoring	No monitoring	Monitored with automatic notification of fire brigade

Occupant characteristics

The occupant characteristics will be identical for the timber (subject) buildings and control (Deemed-to-Satisfy Provisions).

Emergency exit provisions

Emergency exit Provisions are in accordance with the NCC Deemed-to-Satisfy Provisions and are shown in Figure K1 to Figure K3. Maximum travel distance to fire-isolated stair from any point on the floor must not be greater than 20 m.

K4 Analysis of Class 5 Buildings

K4.1 Overview

An analysis was undertaken to compare the fire performance of Class 5 mid-rise timber buildings satisfying the NCC Deemed-to-Satisfy Provisions introduced in the 2016 edition to a control building of non-combustible construction required by the Deemed-to-Satisfy Provisions.in earlier editions of the NCC.

The analysis of Class 5 buildings used the results of the analysis of Class 2 and 3 buildings where appropriate.

The fire risk in office occupancies is very small when compared to residential occupancies as demonstrated in Table K8, which has been derived from Table K4.

Table K8: Comparative risks for residential and office properties.

Parameter	1 and 2 Family Dwellings	Apartments	Offices
Comparative number of fires	55	14	1
Comparative number of civilian fatalities	421	92	1
Comparative risk to life /m² of floor area	24	21	1

It was also observed that:

- Approximately one-third of fires occur outside working hours, but these accounted for approximately two-thirds of direct property damage and civilian fatalities.
- 50% of victims appeared to be intimately involved with the fire start.
- Liquid fuels were involved in 42% of fires in which fatalities occurred (mostly incendiary fires).
- Building fire safety systems would not be expected to impact significantly with respect to injuries and fatalities where the casualties are intimately involved in the fire start.

K4.2 Impact of Fires Within the Fire Compartment of Fire Origin

Since non-loadbearing internal walls bounding corridors and SOUs are not required to be of fire-resistant construction in Class 5 buildings, the potential impact of controls specified on the combustibility or materials used to construct fire-resistant elements on the fire growth rate and fire severity of fully developed fires within the fire compartment of fire origin will be much less than in Class 2 and 3 buildings.

Both the automatic fire sprinkler system (fire-protected timber solution) and the fire detection system (control building solution) are Deemed-to-Satisfy solutions for smoke hazard management, and therefore the impact of smoke spread within the compartment of fire origin does not require further analysis. During normal working hours, occupants are more likely to identify fires quickly, irrespective of the fire detection and alarm system, and fires outside normal working hours will tend to be more critical, as indicated by fire statistics.

Outside normal working hours, if a fire is large enough and the control building fire detection operates successfully, an automatic building alarm will sound but will not automatically call the fire brigade; whereas, if the fire is large enough and the timber building's automatic fire sprinkler system operates successfully, a building alarm will sound, the fire will be controlled or suppressed and the fire brigade will be called automatically.

Therefore, in most instances, the timber building in conjunction with automatic fire sprinklers will present a lower risk than the control building with a fire detection system, since the reliability of fire sprinkler systems is similar or greater than fire detection systems. The only exception could be a fire that is large enough to activate the fire detection system but is not large enough to activate a sprinkler system. Such a fire would present a slow onset of untenable conditions and, since occupants in office accommodation can be expected to be awake and alert, they would be provided with the opportunity to evacuate and/or raise an alarm.

This conclusion was further supported by analysis of fire data indicating that fatalities were 62% lower in properties with automatic wet pipe sprinkler systems and property losses per fire were 46% less when wet fire sprinklers were present.

It was therefore concluded that the proposed timber building, in conjunction with automatic fire sprinklers, will present a lower risk to property and people than the control building within the compartment of fire origin. For both the timber and control buildings, the risk to life would be much lower than Class 2 and 3 buildings with the largest risk being to occupants in intimate contact with the fire outside normal working hours.

K4.3 Impact of Potential Fully Developed Fires Initiating in a Fire Compartment on the Remainder of the Building and Structure

The proof of concept for fire-protected timber was demonstrated in relation to Class 2 buildings with the fire-protective coverings either preventing or delaying ignition to facilitate fire brigade intervention in the low probability event of sprinkler failure.

The results showed a large improvement in life safety, which is to be expected, since a range of mitigation measures have been taken to reduce risks associated with timber structural elements and automatic fire sprinklers have been additionally provided.

It was considered reasonable to undertake a simpler supplementary analysis for office buildings, which is described below..

Risk characterisation

Review of fire data indicated that there is a difference in risk between occupied and unoccupied office buildings. In summary, more fire starts occur during normal working hours when the building is occupied, but greater losses occur outside normal working hours when the building has very few occupants.

In occupied Class 5 buildings, occupants should be alert and awake and responsive to fire cues compared to Class 2 buildings, where occupants could be asleep.

Outside normal working hours, there is greater potential for Class 5 buildings to be unoccupied, reducing the probability of early notification to the fire brigade of a fire.

Occupants are intimately involved with the fire in about 50% of cases and building fire safety systems will have minimal impact on these casualties.

A mid-rise Class 5 timber building, in accordance with the NCC 2016 DtS Provisions, will have automatic fire sprinklers but no smoke detection or smoke alarm system; whereas, for a Class 2 building, both smoke detectors or alarms and fire sprinklers are required. The smoke detection/alarm system is provided in Class 2 buildings to activate an alarm system to alert sleeping occupants. For Class 5 buildings, the Deemed-to-Satisfy Provisions infer that a fire sprinkler system adequately addresses smoke hazard management, since occupants are expected to be awake.

Normal working hours (substantially occupied office buildings)

The Class 2 and 3 building analyses previously undertaken considered a range of fire brigade call times varying from automatic notification by fire detection systems to reliance on notification by occupants or the general public after flashover has occurred. For substantially occupied office buildings, the call time to the fire brigade would be expected to lie within the range considered with a bias towards early notification.

It is therefore reasonable to apply these results for Class 5 buildings, but the improvement in life safety for timber buildings compared to the control Class 5 buildings would not be as great as that predicted for Class 2 and 3 buildings. This is due to the low base risk levels for Class 5 buildings, largely as a consequence of an alert population compared to accommodation that has a sleeping component.

The NCC Deemed-to-Satisfy FRLs for loadbearing elements are equal to or greater than those required for Class 2 and 3 buildings, typically increasing the level from 90 minutes to 120 minutes. The impact of this on timber buildings will either be to increase the protection to timber elements (further delaying or preventing ignition altogether) and/or increasing the inherent fire resistance of a massive timber element, providing a more robust structure.

Therefore, it is considered that the mid-rise timber buildings designed in accordance with the NCC 2016 DtS Provisions for mid-rise buildings would achieve a lower expected risk to life than the control building for fires occurring during normal working hours.

Outside normal working hours (unoccupied office buildings)

If the building is unoccupied, there is a significant probability that the fire brigade will not receive a prompt call in the event of a fire unless a monitored detection or sprinkler system is provided and operates correctly. The delay could be considerable, particularly if the office building is located in an area with few passers-by to observe a major fire.

If the building is unoccupied, the critical matters for consideration are facilitating fire brigade intervention and controlling property losses.

For the timber building options, the provision of a monitored automatic fire sprinkler system will control or suppress the fire and alert the fire brigade, thus facilitating fire brigade intervention and reducing losses. For the control building with no occupants or passers-by, the fire detection system will have no effect on the fire, nor will it alert people to call the fire brigade. For the control building, a greater number of fires will reach flashover and involve a whole fire compartment. Under these circumstances, the timber buildings provide substantially better performance.

A number of stakeholders indicated the importance of considering the reliability of systems and potential for fire spread and ignition of structural members. For the Class 2 and 3 building, preliminary event tree analyses were undertaken and the results subsequently confirmed through Monte Carlo analysis.

The principal differences between Class 2 and 3 and the analysis of Class 5 buildings outside normal working hours are:

- Lower occupant numbers (nil in many cases) reducing the numbers of people exposed to risk but also delaying alarm call unless there is an automatic alarm
- Increased FRLs required for some structural members requiring greater protection and hence reducing the risk of timber members igniting and improving resistance to burnout.
- Experimental data indicating that in many instances the severity of office fires may be less than that of an equivalent 30-minute standard fire resistance test.

It was therefore considered that construction of simple event trees with estimated probabilities for key events was an appropriate method to compare the Class 5 timber buildings with the control building for the 'outside normal working hours' scenario. The table of inputs and event trees and are shown in Table K9 and Figures K4 through to K6.

Table K9: Input summaries for event trees.

Input description	Control input	Lightweight timber input	Massive timber input
Sprinkler system controls/ suppresses the fire	0 probability assigned No sprinkler system provided	0.88 probability assigned from stats. Note: automatic notification of fire brigade assumed not to happen if sprinkler system fails to control the fire	0.88 probability assigned from stats. Note: automatic notification of fire brigade assumed not to happen if sprinkler system fails to control the fire
Defects reduce FRL of 1 element	0.92 probability assigned Based on Class 2 analysis and applied to all options	0.92 probability assigned Based on Class 2 analysis and applied to all options	0.92 probability assigned Based on Class 2 analysis and applied to all options
Defects reduce FRL of more than 1 element	0.999 probability assigned assigned to all options	0.999 probability assigned Assigned to all options	0.999 probability assigned Assigned to all options
Fire brigade intervention before ignition of timber element	0 non-timber option	0.98 assigned if no defects since high level of protection provided and consideration of nature of fire load 0.5 assigned with defects since greater risk of ignition but impact of nature of fire load considered	0.9 probability assigned if no defects, since less protection provided to massive timber, but nature of fire load generally (less than 30 minute equivalent FRL) reduces probability of ignition 0.5 assigned with defects, since greater risk of ignition, but impact of nature of fire load considered
Fire brigade Intervention before potential equivalent FRL exposure	0.99 assigned if no or one defect due to high levels of passive protection; reduced to 0.5 if two or more defects	0.5 assigned – generally conservative value but also takes account of proportion of fires with fire brigade intervention before ignition of timber	0.9 assigned if no defects and 0.5 assigned for other cases – generally conservative value but also takes account of proportion of fires with fire brigade intervention before ignition of timber
Compartment withstands burnout.*	0.9 no defects; 0.8 one defect; and 0.7 more than one defect values assigned, taking into account fires assumed already suppressed by fire brigade	0.9 no defects, 0.7 one defect and 0.2 more than one defect values assigned, taking into account fires assumed already suppressed by fire brigade Lower values assumed for timber to take account of potential ignition if defects are present	0.6 no defects; 0.4 one defect; and 0.2 more than one defect values assigned, taking into account fires assumed already suppressed by fire brigade Lower values assumed for massive timber to take account of potential ignition if defects are present and lower levels of protection of timber
Fire spread/ major collapse resisted	1 assigned if one or fewer members fail; 0 assigned if more than one fails	1 assigned if one or fewer members fail; 0 assigned if more than one fails	1 assigned if one or fewer members fail; 0 assigned if more than one fails

Based on full-scale fire tests summarised in Table K3, fire exposure from the simulated office fires were equivalent to exposure to the standard fire resistance test for between 20 and 28 minutes. Therefore, even with gross defects, there would be a reasonably high probability that the compartment would resist burnout.

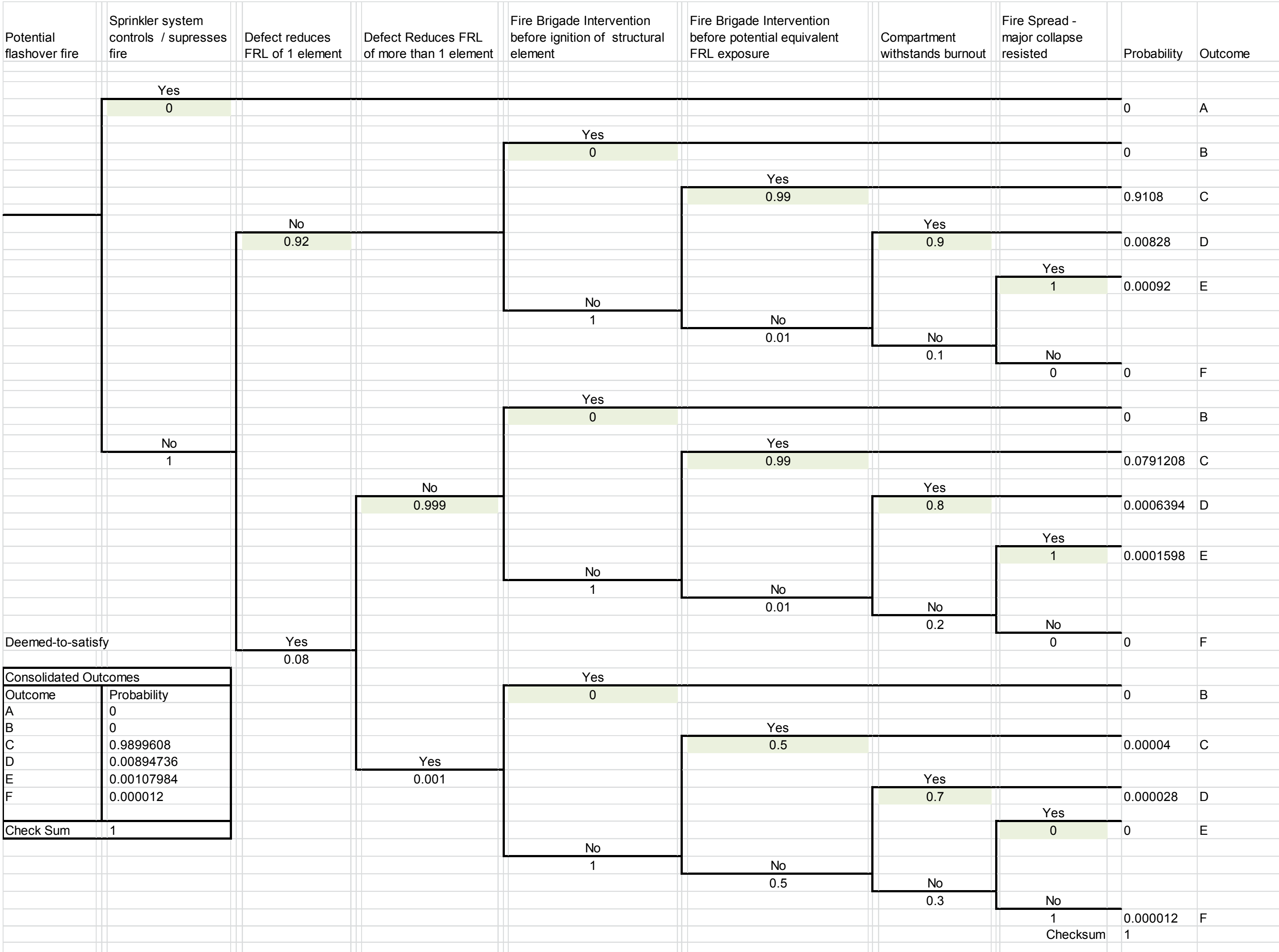


Figure K4: Event tree for control building.

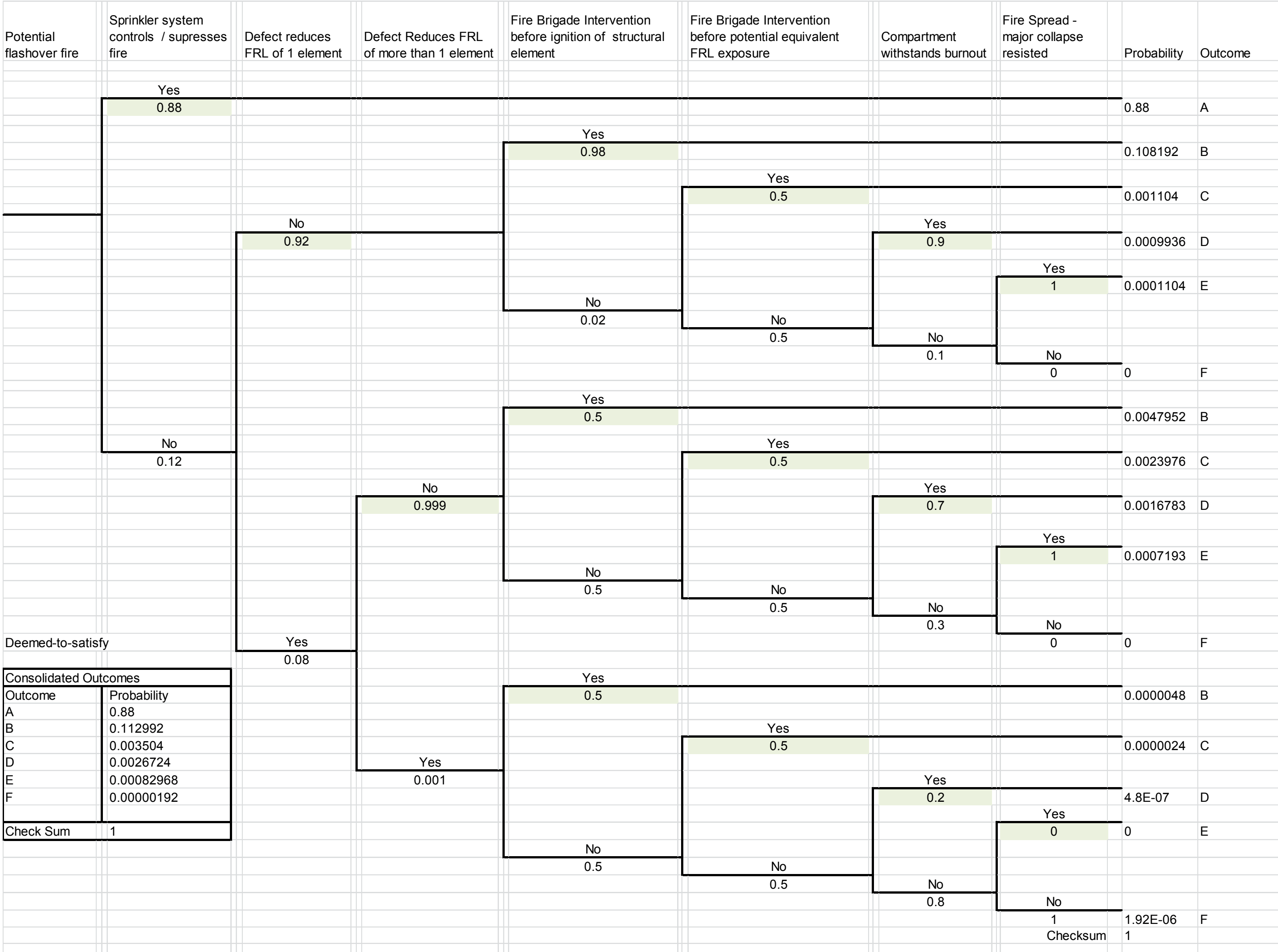
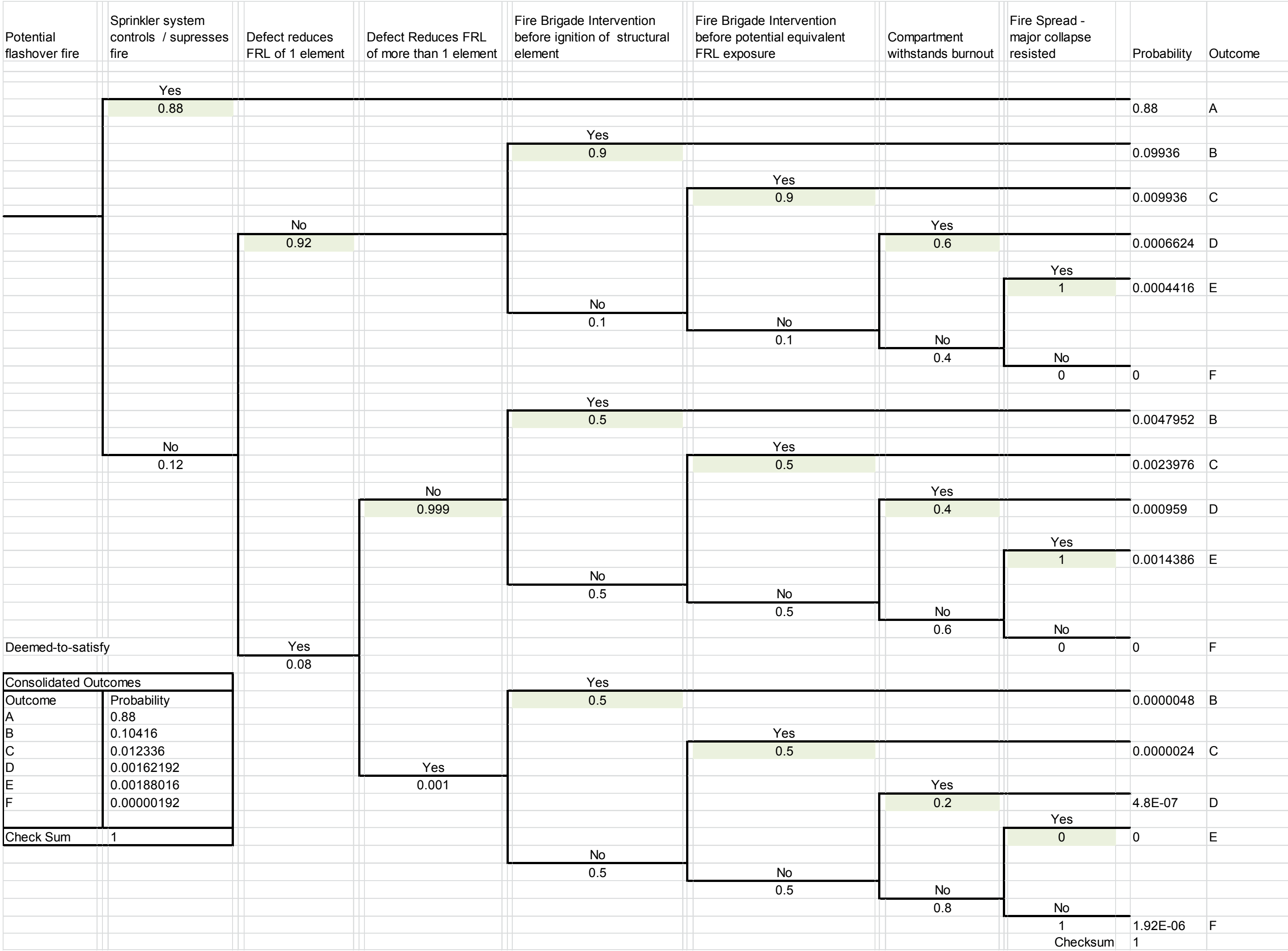


Figure K5: Event tree for lightweight timber building.



Consolidated Outcomes	
Outcome	Probability
A	0.88
B	0.10416
C	0.012336
D	0.00162192
E	0.00188016
F	0.00000192
Check Sum	1

Figure K6: Event tree for massive timber building.

The results are summarised and compared in Table K10.

The sprinkler-controlled outcome represents a lower expected property loss and also minimises the risk to fire fighters, representing by far the lowest risk outcome.

Outcomes B, C and D can be viewed as being consistent with the intent of compartmentation in the NCC, i.e. containing fires within the compartment of fire origin.

Outcomes E and F occur as the result of gross defects and multiple failures of systems and, as the results confirm, are very low probability events.

Table K10: Results from comparative analysis of no-occupant scenarios.

Ref	Outcome	Probability of outcome		
		Deemed-to-Satisfy	Massive timber	Timber-framed
A	Sprinkler controlled	0	0.88	0.88
B	Fire brigade intervention before ignition of structural element	0	0.1042	0.1130
C	Fire brigade intervention before equivalent FRL period	0.989961	0.012336	0.003504
D	Compartment withstands burnout without FBI	0.00894736	0.001622	0.002672
E	Fire spread without major collapse	0.00107984	0.001880	0.000830
F	Major structural collapse	0.000012	0.000002	0.000002

Based on these results, it was concluded that the provision of automatic fire sprinkler protection in conjunction with fire-protected timber provides an acceptable level of protection.

K4.4 Impact of Fires in Fire-isolated Stairs and Passageways

The analysis undertaken for Class 2 and 3 buildings was considered valid for Class 5 Buildings.

K4.5 Fire Spread via the Façade

The analysis undertaken for Class 2 and 3 buildings was considered valid for Class 5 Buildings.

K4.6 Fire Spread between Buildings

The analysis undertaken for Class 2 and 3 buildings was considered valid for Class 5 Buildings.

K4.7 Fires in Lifts

The analysis undertaken for Class 2 and 3 buildings was considered valid for Class 5 Buildings.

K4.8 Fire Spread via Concealed Spaces

The analysis undertaken for Class 2 and 3 buildings was considered valid for Class 5 Buildings.

L

Appendix L: Peer Review Letter

SKIP
CONSULTING PTY LTD

28 April 2016

Mr Boris Iskra
National Codes and Standards Manager
Forest & Wood Products Australia
Level 4, 10-16 Queen St
Melbourne, VIC 3000

Dear Boris,

Re: **Technical Review of WoodSolutions Technical Guide #38**

Thank you for inviting us to review the document WoodSolutions Technical Guide #38 - Fire Safety Design of Mid-rise Timber Buildings which has been prepared by EFT Consulting on behalf of Forest and Wood Products Australia. We have reviewed a number of drafts of this document and provided considerable feedback to EFT Consulting with respect to technical matters and clarity of presentation. The final version of Technical Guide #38 is a significant improvement over the initial draft and has incorporated the suggested and other changes.

We understand that the purposes of Technical Guide #38 are:

(a) To clearly describe and explain the changes the National Construction Code, Volume One 2016 (NCC 2016) with respect to fire-protected timber, and
(b) To give the technical basis for these changes, and
(c) To provide guidance on the level and type of analysis required should a Performance Solution involving-fire protected timber need to be developed.

The technical basis presented in this document is the same as that described in Report No. EFT 2528 which provided the basis for the changes to NCC 2016 in relation to the use of fire-protected timber. The technical basis as presented in Wood Solutions Technical Guide #38 is both transparent, and detailed and as stated in relation to EFT 2528, is considered to provide an appropriate and adequate justification for the NCC changes.

WoodSolutions Technical Guide #38 has been structured in such a way as to assist those seeking to better understand the fire-protected timber provisions of NCC 2016 without necessarily requiring a detailed understanding of the technical basis but it also provides the detailed technical arguments, information and guidance needed by a fire-safety engineer who is considering developing a Performance Solution utilising fire-protected timber. We therefore consider that the document achieves the stated purposes.

If we can assist further, please do not hesitate to contact the undersigned.

Yours Faithfully

Dr Ian Bennetts
BE (hons), M Eng Sc, PhD
FIE (Aust) NER (civil) NER (fire safety)

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M

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AS 1530.4-2005 Methods for fire tests on building materials, components and structures – Fire-resistance test of elements of construction Standards Australia 2005

2021 Supplementary Notes

Introduction

WoodSolutions Technical Design Guide 38 [1] provides details of the technical supporting data and fire engineering analysis that was undertaken to evaluate the potential impact of the inclusion of a Deemed-to-Satisfy (DtS) pathway for mid-rise Class 2, 3 and 5 fire-protected timber buildings that was subsequently included in the National Construction Code Volume One [2] (NCC 2016).

The body of the guide has not been updated since the analysis was undertaken and uses the terminology and content of the (then) proposed NCC 2016 edition. However, the fire engineering analysis and supporting data still has relevance to potential Performance Solutions.

These supplementary notes identify some relevant changes to the NCC and interpretations of the NCC through the publication of Amendment 1 to NCC 2016 Volume One [3], NCC 2019 Volume One [4] and Amendment 1 to NCC 2019 Volume One [5].

Significant changes to the NCC's structure and terminology have been made since 2016 as part of an initiative to improve its readability. The primary purpose of the restructure was not to materially modify the NCC but to clarify its intent and hence facilitate compliance. The amendments included some technical changes as part of the routine revision cycle for the NCC.

To assist readers of Technical Guide 38, the more relevant changes are summarised below.

General changes to NCC Volume One – structure and terminology

Some of the more relevant changes to the content of Guide 38 are:

- General Provisions have been replaced with a new Section A 'Governing Requirements'
- Substantial amounts of content has been moved to Schedules
- Performance Requirements have been provided with headings
- New Verification Methods have been introduced and changes made to some existing Verification Methods
- The term Registered Testing Laboratory has been replaced with Accredited Testing Laboratory (ATL).

As a result, relevant clause numbers and locations within the NCC of the content relating to fire-protected timber mid-rise building DtS solutions have changed, but the relevant technical provisions remain the same. Figure S1 identifies the current location of the relevant content in the NCC and should be used in lieu of Figure 4.1 in the body of Guide 38 if the NCC Volume One 2019 edition is being referred to instead of the NCC 2016.

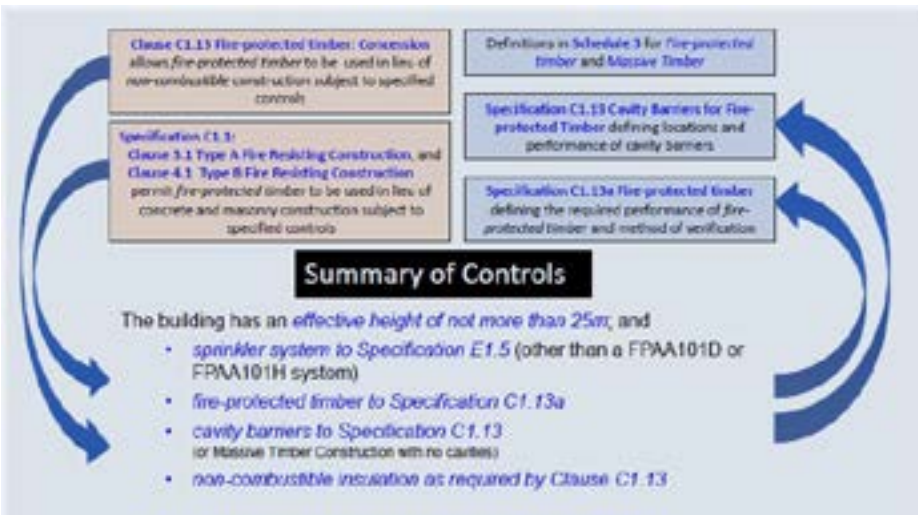

Figure S1: Summary of fire-protected timber controls based on NCC 2019 Amd 1.

Verification methods

BV1 has been revised and provides a means of verifying the reliability of structural components that may have relevance to the robust design of mid-rise timber structures (addressed in more detail in WoodSolutions Technical Design Guide 39). Technical Design Guide 38 includes information on the reliability of fire protection systems, including fire-protective coverings and methods of analysis suited to quantified fire risk assessments.

CV3 provides a verification method for Performance Solutions demonstrating compliance with Performance requirement CP2 to avoid the spread of fire via the external wall of a building when involving combustible external facades. As NCC C1.13 allows fire-protected timber to be used where an element is required to be non-combustible, the addition of CV3 provides another option to determine compliance with CP2 if combustible materials are applied to the external wall, such as a combustible external weather screen. The content of Technical Design Guide 38 does not require adjustment.

CV4, DV4, EV1.1 – The fire safety verification method applies a holistic comparative approach to the assessment of Performance Solutions and nominates a number of scenarios that should be analysed. This approach is consistent with the analysis methods adopted to justify the changes to the NCC allowing the use of fire-protected timber and so Technical Design Guide 38 provides a useful resource to support the introduction of the fire safety verification method in the NCC.

Extension of fire-protected timber concession to all building classes

The concession for the use of fire-protected timber was extended to all classes of buildings generally using similar analysis methods to those used for Class 2, 3 and 5 buildings that were the focus of the 2016 revision of the NCC and content of Technical Design Guide 38.

Non-combustibility

Provisions relating to combustibility within the NCC have been reviewed and revised since the 2016 edition to improve clarity and building compliance, with an emphasis on external walls. These changes do not affect the relevance of the analysis described in Technical Design Guide 38 but still apply to mid-rise fire-protected timber buildings if the DtS pathway is followed. A useful summary of the changes is provided in the ABCB publication 'Fire performance of external walls and cladding – Advisory Note' [6].

FPAA101D and FPAA 101H sprinkler systems

Two automatic fire sprinkler system design codes were introduced for use in some mid-rise residential Class 2 and 3 buildings. These sprinkler systems have reduced coverage and flow rates, among other things, compared to other sprinkler systems prescribed by Specification E1.5 of the NCC and were not evaluated as part of the analysis described in Technical Design Guide 38. The reduced coverage and flow rates would reduce the efficacy and reliability of a sprinkler system, and this would increase the risk to life calculated for the mid-rise timber buildings if the FPAA101D and FPAA101H sprinkler systems were used. ***The NCC 2019 DtS solution for mid-rise fire-protected timber buildings does not permit the use of FPAA101D and FPAA101H sprinkler systems.***

Other Relevant WoodSolutions Technical Design Guides

Technical Design Guides 37R, 37H and 37C [7-9] have been updated to provide guidance on the design of fire-protected timber mid-rise timber buildings using the DtS pathways defined in the NCC 2019 Amd 1 edition.

Technical Design Guides 17[10] and 18[11] have been rewritten to provide additional methods and data to support the design of timber buildings using a Performance Solution pathway and applying holistic approaches consistent with the fire safety verification method and quantification of performance requirements that are likely to be introduced in the NCC 2022.

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