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Timber-framed Systems for External Noise

Technical Design Guide issued by Forest and Wood Products Australia

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Introduction

This guide has been prepared to assist the building industry with the key issues to be considered when assessing alternatives related to external noise using lightweight timber-framed construction. The information contained in this guide should not be considered as standalone, and where appropriate relevant expertise should be obtained. The guide does not cover matters associated with other aspects of building construction or the regulatory requirements associated with these.

Noise – it's everywhere. It impacts on our daily lives, in our homes, work places and during recreational pursuits. Many factors can and will influence the degree of unwanted noise that enters our homes and our response to this, including:

- Owner/occupier expectations
- Daytime or nighttime
- Ambient background noise levels
- Activities being undertaken

One of the most significant sources of unwanted external noise comes from transportation activities – road, rail and aircraft.

In order of priority there are three main strategies for reducing the intrusion of unwanted external noise into residential properties:

- Distance separation between the noise source and the property
- External physical noise attenuation barriers
- Noise attenuation of the building envelope

Where the first two methods cannot be satisfactorily achieved, many regulatory juristictions are now imposing limits on the entry of noise into the habitable areas of dwellings by controlling the design and construction of the building envelope (roofs, walls and floors).

Key Issues

When designing a new or modifying an existing dwelling, all building work must comply with the Building Code of Australia (BCA) and any actions to reduce the ingress of external noise must be designed and constructed to be compatible with all other aspects of the BCA that may apply such as energy efficiency and bushfire construction requirements.

Considerations include:

- Inner cities tend to generate greater levels of external noise than suburban areas with low frequency noise from sources such as trucks, construction sites and waste collection being more problematic.
- In suburban areas, residences close to main road and rail corridors may suffer from unwanted noise and residences close to airports or flight paths may also be exposed to noise sources that need to be addressed.
- The openings in the external building envelope including the number, size, location and selected materials for windows and doors will have a major impact on the control of noise that can enter a building. Careful consideration should be paid to these prior to any upgrading of the exterior walls, floors and the roof-ceiling system.

1

Methods for Reducing Noise into Buildings

In order of priority there are three main options for reducing the intrusion of external noise into residential properties:

- **Adequate distance separation between the noise source and the property (set-backs and separation strips)**
- **Physical barriers including noise attenuation barriers (fences, walls etc and appropriate landscaping and vegetation) and**
- **Building noise attenuation into the building envelope (walls, floors and roofs)**

1.1 Site planning and landscaping

Some of the principles for planning and arranging residential dwellings on a site to help manage and minimise the intrusion of noise from transport sources include:

- using natural features such as contours and slopes in the siting of dwellings to provide shielding from noise sources
- using material excavated on site to form mounds around the building to provide protection
- physical separation by using as much distance as possible between the noise source, such as a road, and the residence
- locating non-sensitive buildings and spaces that are noise tolerant such as landscaped areas, carparks, open space and garages between the noise source and the more sensitive residential development. On a larger scale, open space, recreation areas or commercial facilities could be used to separate noise sources from residential areas
- using structures as a barrier to protect or shield the areas behind such as placing garages, courtyards and similar between the noise source and the dwelling

(Image courtesy of ASK Consulting Engineers)

1.2 Site specific assessment and design

In many instances, developers and builders report that it is far more beneficial and economical to engage acoustic consultants to undertake site specific assessment and design where external noise sources are required to be addressed in residential construction.

This process typically involves the following steps:

- determine the level of existing external noise exposure (either through site measurements or modelling)
- determine external treatments that can be applied to emiliorate external noise (if this option is available)
- determine the facade (openings, walls roofs and floors) treatment that is required
- certification upon completion of work

The Association of Australian Acoustical Consultants (AAAC) have published a guide on levels of acoustic amenity to provide differing levels of building quality. Ratings range from 2 to 6 stars and are based on field testing by an AAAC consultant to verify that they have been achieved. More information about AAAC Star Ratings for dwellings, apartments and townhouses is available at www.aaac.org.au

1.3 Building Envelope Noise Attenuation

Walls including openings, roofs and floors in the external building envelope can be designed and constructed to minimise the intrusion of unwanted external noise.

Many regulatory juristictions are now imposing limits on the entry of noise into the habitable areas of dwellings by controlling the design and construction of the building envelope (roofs, walls and floors).

The following section considers some of the regulatory requirements and provides solutions in lightweight timber construction to meet these requirements.

2

Regulatory Requirements

Across Australia, many levels of Government and their authorities have regulatory or legislative powers to require control of noise entering buildings, in particular residential buildings. These requirements tend to be fairly 'fluid' with regular changes requiring designers and specifiers to keep abreast of new initiatives.

Examples of these requirements include, but are not limited to:-

• noise overlays for aircraft and airport environments

• road noise corridors

• rail noise corridors

Control and application of these requirements may rest with local governments or state authorities such as Departments of Building and Planning, Transport or Main Roads etc, and in some cases (aircraft) at the Federal level.

At the time of publication of this Guide, there were no requirements for the control of external noise entering buildings contained within the BCA, however, these were under consideration by the Australian Building Codes Board with draft changes proposed.

2.1 Local Authority Requirements.

In response to community concerns, many local authorities have been requiring building envelope treatment for residences which are not protected sufficiently by noise barriers. At the same time some councils have been restricting the heights of noise barriers for reasons of visual amenity, limiting the level of noise reduction that can be attained. In conjunction with this height restriction, additional noise insulation requirements have been placed onto residential allotments which are affected by unreasonable levels of noise. These requirements have been enforced by either planning instruments, property notes or covenants to the title.

2.2 State and Territory Requirements

A number of states and territories have legislation that requires developers, designers, certifiers and builders to limit the intrusion of external noise into residential and other types of building occupancy.

Before considering or applying any external noise control options, consult with your relevant state/territory body to determine the specific requirements that need to be addressed which may vary from significant requirements to none.

Some typical examples for some States and Territories are listed below.

New South Wales

Road Traffic Noise

The NSW State requirements for road traffic noise for residential development are contained within the State Environment Planning Policy (Infrastructure) 2007 Clause 102 – Impact of Road Noise or Vibration on Non-road Development. This clause states that if the development is for the purposes of a building for residential use, the consent authority must not grant consent to the development unless it is satisfied that appropriate measures will be taken to ensure that the following energy averaged noise levels (LAeq) are not exceeded; (a) in any bedroom in the building - 35 dBA at any time between 10 pm and 7 am, (b) anywhere else in the building (other than a garage, kitchen, bathroom or hallway) - 40 dBA at any time.

Rail Traffic Noise

The NSW rail noise and vibration requirements are found, for example, in Infrastructure SEPP Clause 87 Impact of Rail Noise or Vibration on Non-Rail Development 2007, NSW. Clause 87 states that if the development is for the purposes of a building for residential use, the consent authority must not grant consent to the development unless it is satisfied that appropriate measures will be taken to ensure that the following energy averaged noise levels (LAeq) are not exceeded; (a) in any bedroom in the building - 35 dBA at any time between 10 pm and 7 am, (b) anywhere else in the building (other than a garage, kitchen, bathroom or hallway) - 40 dBA at any time.

Aircraft Traffic Noise

An acoustical report to comply with the Australian Standard AS 2021 – 2000 "Acoustics – Aircraft Noise Intrusion - Building Siting and Construction" is often required by Council's Development Consent for sound insulation against air traffic noise.

Queensland

Traffic Noise

The Queensland Development Code (QDC) MP 4.4 "Buildings in transport noise corridors" provides for construction standards for minimum traffic noise reduction levels which are to be achieved across four noise categories. These noise categories provide for a weighted sound reduction index (R_w) which determines appropriate building materials for the floor, walls, roof, windows and doors. These building materials are to restrict the amount of external noise entering habitable rooms of a residential building.

Mandatory Part (MP) 4.4 was introduced into the Queensland Development Code (QDC) on 1 September 2010. QDC MP 4.4 is to be used by building certifiers when assessing residential buildings within a transport noise corridor'.

A Transport Noise Corridor is defined by agencies such as the Department of Transport and Main Roads (TMR), Queensland Rail and local authorites. At the time of this study, corridors had only been assigned by TMR for most major roads in Queensland. The Code defines five noise categories based on the noise exposure level. Category 4 is the highest and Category 0 the lowest.

The categories are assigned based only on the distance from the road and the characteristics of the road and do not account for constructed noise barriers and terrain features which may shield properties.

The Code allows a reduction in the noise category using a noise model to predict the noise exposure which can account for screening effects from barriers, terrain and other buildings present between the road and the residence being assessed. This typically results in a reduction in the noise category. For each of the noise categories the following ratings are required by QDC MP 4.4:

Noise Reduction Performance for Various Building Elements

Category	Building Element Sound Reduction Requirement (Rw)				
	Glazing (Area Dependent)	External walls	Roof	Floors	Entry Doors
Category 4	43	52	45	51	35
Category 3	35-38	47	41	45	33
Category 2	32-35	41	38	45	33
Category 1	24-27	35	35	NR	28
Category 0	No additional acoustic treatment required – standard building assessment provisions apply.				

Note: NR = Not required

Victoria

In Victoria there are no specific, statewide regulations for noise, however the special noise control overlay for Melbourne Airport does introduce some requirements, see specific noise control section below.

Australian Capital Territory

In the ACT, the mechanisms available for management of noise levels include:

- regulation of noise emissions at the source (Noise Control Act 1988 administered by the Pollution Control Authority);
- planning control over land use and set-back distances, and design of buildings, necessary to separate noise generating activities from noise sensitive land uses;
- planning and development requirements for provision of noise attenuation measures, including building design, materials used and construction techniques/practices.

Traffic Noise

A draft Noise Management Guidline has been published by the ACT Planning Authority which sets out guidelines for desirable and maximum levels of noise from traffic and land use activity, and advises on methods to prevent or reduce excessive noise levels. The guidelines do not remove the requirement to comply with the Noise Control Act 1988.

The objectives of the noise management guidelines are to ensure that:

- developments with the potential to introduce new noise sources, whether a road or a land use activity, are designed to ensure that noise in adjacent areas is kept within acceptable limits; and
- new noise-sensitive developments are protected from unacceptable noise levels generated by existing sources.

Western Australia

In most cases transportation noise is not subject to the Environmental Protection (Noise) Regulations 1997 because it is regulated by one of several other means.

Vehicle Noise
Traffic noise from roads is exempt from the Environmental Protection (Noise) Regulations 1997. Instead, the Road Traffic (Vehicle Standards) Rules 2002 address community concern about noisy trucks, cars and motorbikes.

Rail Noise
Noise emissions from rail are exempt from the noise regulations.

Aircraft Noise
Whether it is as a result of ground operations or from aircraft whilst in flight, it is covered under federal legislation and managed by an Aircraft Noise Strategy.

Specific Noise Control
In a number of specific situations, special overlays may apply to certain areas. For instance the The Melbourne Airport Environs Overlay is a set of planning rules, or controls, designed to help state and local government plan for the environmental effects of aircraft noise associated with Melbourne Airport.

2.3 National Construction Code Series - Building Code of Australia (BCA)

Currently there is no National code for external noise, however the Australian Building Code Board had drafted amendments proposed to address external noise intrusion for consideration by the BCA. At the time of publication of this guide the BCA had requested further consultation and development of the proposal.

3

Lightweight Timber Solutions

3.1 Introduction

The Weighted Sound Reduction Index (R_w) and Low-frequency Spectrum Adaptation Term ($R_w + C_{tr}$) ratings for various systems given in Sections 3.6 to 3.8 have been derived using information from existing published tests and calculations of performance using the 'Insul' computer software. This information is based on a report provided by acoustic consultants.

3.2 Definitions

Weighted Sound Reduction Index (R_w)

The Weighted Sound Reduction Index (R_w) refers to a single number acoustic rating calculated from the reduction in noise between two rooms. A higher rating indicates less sound transmission and higher performance. Rw is assessed over the frequency range 100-3150Hz using the sum of deviations less than 32 dB method and is calculated using formulae in AS/NZS/ISO 717.1 2004 Acoustics---Rating of sound insulation in buildings and of building elements Part 1: Airborne sound insulation.

Low-frequency Spectrum Adaptation Term ($R_w + C_{tr}$)

The $R_w + C_{tr}$ parameter is also calculated using formulae in AS NZS ISO 717.1 2004

The C_{tr} term refers to a correction factor that adjusts the R_w to take into account low frequency noise. If the noise being transmitted contains a large element of low-frequency noise, then the correction factor will lower the Rw rating to reflect this low-frequency noise intrusion. For nearly all building elements, low frequency transmission is poorer than for speech therefore the Ctr term is usually negative.

STC

STC or Sound Transmission Class is a single number rating for partitions. It is calculated or derived from 1/3 octave band Sound Transmission Loss data by a method described in American Society for Testing Materials standard ASTM E316. The frequency range for assessment of STC is 125-4000 Hz. It also uses the sum of deviations less than 32 dB method and includes a limitation of no octave more than 8 dB below the rating curve.

In general the two ratings (STC and R_w) give either the same number or are only 1-2 points difference, so they can be used fairly interchangeably.

3.3 Calculation of Acoustical Performance

Levels of acoustic performance have been calculated using the industry standard 'Insul' software. (http://www.insul.co.nz/). Allowances have been made for mass of various materials and "ideal" workmanship. Publishers of the 'Insul' software claim that comparisons with "calculated performance" with test data show that it is generally within 3 STC/Rw points for most constructions.

Factors taken into account in calculation of acoustical performance include the surface mass of the material, Young's Modulus, edge damping, the critical frequency and speed of sound in materials, the effect of air cavities and acoustic insulation between members. The R_w values determined and provided in this guide are laboratory values. These estimations of performance can be used for requirements of performance stated in building or planning regulations and other calculation methods, such as AS3671, which also refer to laboratory values.

3.4 Guidance and assumptions for acoustical performance

The performance estimates are based on laboratory quality construction with a high attention to detail. Calculated levels of performance are based on:

- external wall elements being sealed to near-to-air-tight construction which is fully caulked and sealed
- internal plasterboard layers are constructed, caulked, sealed and using details as recommended by the plasterboard manufacturer

Opinions of performance may not be valid where installation details such as stud spacing and fixing centres do not match those used in the nominated systems.

The systems are specifically derived for external noise intrusion and no consideration is given to internal wall construction noise ratings i.e noise travelling between internal rooms. No references are made for the rating of impact noise as impact noise is not an issue for external noise intrusion.

The issue of flanking noise is not considered as estimates are laboratory based and flanking is purposely controlled. For application in the field, flanking should be carefully considered to ensure performance is delivered. If the selection of the acoustical performance of building elements are being made to deliver a result in the field which is not in accordance with a requirement which requires laboratory acoustical performance, an acoustic consultant should be consulted to provide detailed recommendations for construction.

Timber Types

Acoustical opinions were provided for the following wall constructions:

- 70mm studs are 35 or 45 mm thickness
- 90mm studs are 35 or 45 mm thickness
- may consist of softwood, hardwood or engineered timber product
- in standard walls, noggins may be full depth of stud or alternatively lesser depth as per AS 1684
- for the use of staggered studs, where noggings are installed, noggings on the outer studs must not touch the inner studs and vice versa. This may necessitate the use of thin noggings on edge. A typical staggered stud arrangement without noggings is shown in Figure 1
- For pitched roof/ceiling systems, cathedral ceilings and floor construction all timber product types are acceptable including solid timber and engineered timber products such as 'I' joists, LVL, Glulam and trusses.

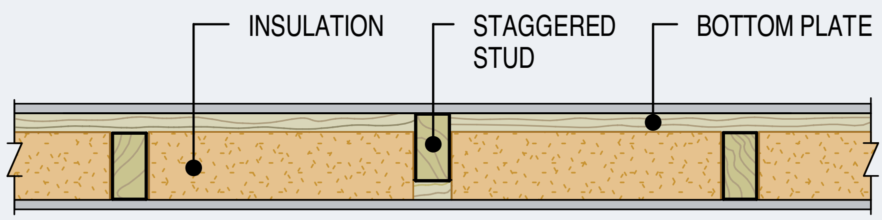


Figure 1: Plan view of Staggered stud wall system

Insulation

(a) Glasswool (GW)

Insulation nominated in this guide is glasswool. Glasswool insulation has been used as there is an Australian Standard for glasswool manufacture and the product remains consistent.

Any glasswool insulation of greater thickness and density to that nominated can be substituted to achieve better acoustic insulation. This additional insulation will improve performance to a value greater than the estimates. In most cases the addition of further insulation either by thickness or density will slightly improve the performance of a system, particularly at low frequency; however the overall improvement may only be 1 dB.

Insulation used should not be thicker than the cavity size as bridging can occur.

Should an upgrade in acoustical performance above and beyond the values provided in this manual be required with the addition of insulation, advice from an acoustic engineer should be sought.

(b) Polyester Insulation

The substitution of polyester insulation is acceptable for the nominated systems on the basis that equivalent or better thickness and density is provided.

Care should be taken when using polyester insulation as there is currently no Australian Standard for its manufacture. Should there be any concern over quality of product used in substitution advice from an acoustic engineer should be sought.

Plasterboard

Where plasterboard is referred to in this manual it is plasterboard constructed in accordance with: AS/NZS 2588:1998 Gypsum Plasterboard.

Minimum permissible masses are as follows:

- 10mm plasterboard (Pbd): 6.5kg/m2
- 13mm plasterboard (Pbd): 8.5kg/m2
- 16mm fire-rated plasterboard (FR Pbd): 12.5kg/m2

Ventilated Eaves

A common feature of timber framed building is the use of ventilated eaves which are connected to the roof cavity. Ventilated eaves result in acoustical weakness unless treated correctly.

It is acknowledged that the use of ventilated eaves are necessary in specific situations. In areas where buildings require acoustical ratings of external elements, detailing is required to preserve acoustical integrity of the building through this path. One method of addressing this is to provide glasswool packed tightly over top plates of walls under the roof sheeting/tiles.

In situations where consideration is given to orientation of the building to a noise source, ventilation of a roof space can be achieved by orientation of the ventilation slots/holes on the leeward side of the building.

Resilient Steel Wall Channels

Where nominated in the details and ratings in Section 3.6, resilient steel wall channels may be fixed vertically to studs or horizontally across studs in accordance with manufacturers requirements.

The channels may also be located on either the inside of the wall or the outside of the wall without affecting the acoustic ratings given.

Where located on the external side of the wall to support cladding, particular attention should be paid to manufacturers recommendations regarding installation to resist relevant wind pressures.

Figure 2 illustrates a typical proprietary side fixed resilient wall channel used to support the internal lining.

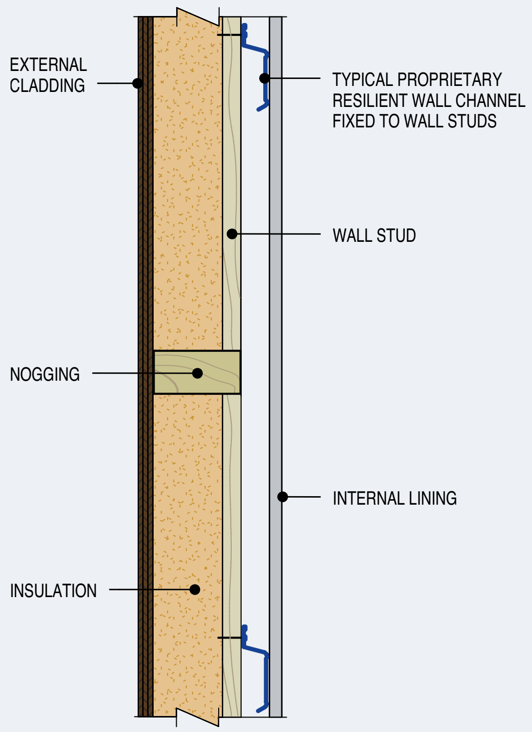


Figure 2: Resilient mounted wall cladding. Vertical section through wall

Resilient Mounted Ceilings

Where ceilings are required to be resiliently mounted, the typical detail given in Figure 3 may be used.

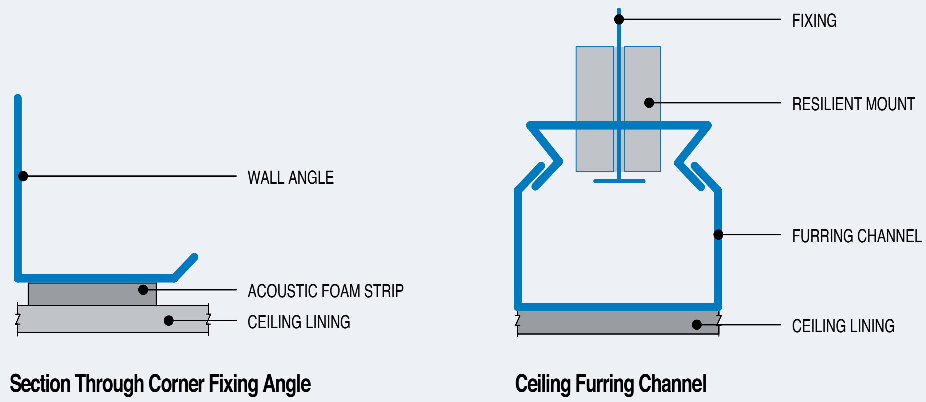


Figure 3: Resilient mounted ceiling lining. Resilient mount and furring channel detail

Floor Zones

Ratings are nominated in this guide for elevated floors which are open to the exterior via an opening. Perimeter sub-floors covered with open mesh, slats or perforated material which allow the air to freely pass do not provide a noise reduction and the ratings in the table should be used without adjustment.

In situations where the underfloor area is built-in around the perimeter of the building with the minimum BCA ventilation opening requirements, an improvement to the noise transmission path through the floor is provided. With the opening requirement of 7500mm^2/m of wall length not being exceeded, using continuous brick, block, or, fibre cement linings, an estimated improvement to the R_w and R_w+C_{tr} rating of the floors is 15 dB. For continuous 0.42mm BMT metal sheeting which is connected to solid elements at the periphery an improvement of 10 dB is expected with the minimum opening requirement.

3.5 Substitutions

In using the nominated opinions in this guide, it is possible that a slightly different system may be sought. If changes to a system are made, the changes will modify the acoustical performance in the following ways:

Cavity, insulation and sarking changes

- Increasing the thickness and density of the insulation will improve the performance slightly. Polyester insulation of equivalent or greater thickness and density may be substituted for the Glass Wool (GW) insulation.
- Increasing the cavity between the inner and outer layer will improve the performance.
- Omission of wall or roof sarking will not effect the acoustic ratings
- When a batten is used on the outer layer of the system, sheeting elements can be grouped together or separated using the batten without affecting the performance.

Stud Changes

- Increasing the thickness of studs and battens will decrease the performance and should be avoided.
- For systems using 70mm studs and batten a 90mm stud without batten may substituted without changing the performance.
- For wall systems other than Brick veneer and staggered studs, the reduction of stud spacing from 600mm centres to 450mm centres reduces the Rw and Rw+Ctr performance by 1 dB due to the additional connections.
- For brick veneer and staggered studs wall systems, there is no reduction in R_w and R_w+C_{tr} performance changing the stud spacing from 600mm to 450mm.
- Bridging staggered studs with noggings will negate the performance improvements back to that of a normal stud wall

Sheeting and lining Changes

- Medium Density Fibreboard (MDF) of equivalent density to plasterboard can be substituted for plasterboard and the same degree of performance obtained if the same arrangements of caulking and sealing are applied as per the plasterboard.
- Fibre cement sheeting (6mm thickness) provides slightly better acoustical performance than standard-core plasterboard and can therefore be substituted for 10 or 13mm plasterboard in any of the systems using 10 or 13 mm plasterboard and the same performance achieved.
- One layer of 10mm plasterboard plus one layer of 16 mm plasterboard may be substituted for two layers of 13 mm plasterboard.
- Hardboard (6.4mm) thickness provides equivalent acoustical performance to standard-core plasterboard and can therefore be substituted for 10mm plasterboard in any of the systems using 10mm plasterboard.

For any other substitutions, or for the application of any other special proprietary systems or cladding, advice from an acoustic engineer should be sought.

3.6 Wall Systems

3.6.1 Timber External Cladding

(i) Weatherboards (Board lap joints to be caulked)

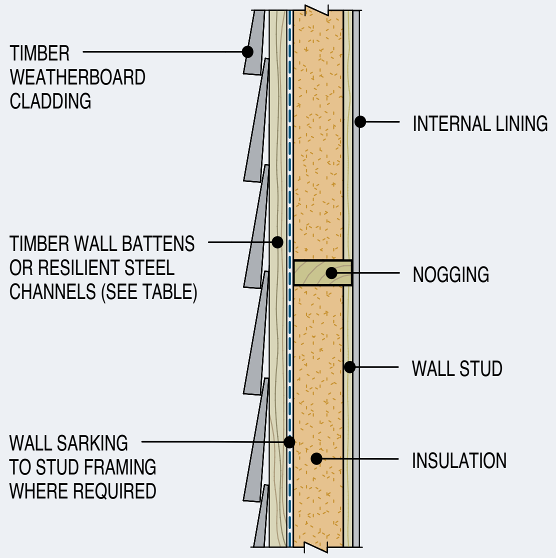


Figure 4: Weatherboard cladding. Vertical section through wall

External Cladding	Batten	Frame	Stud Centres (max)	Internal Lining	Insulation	R_w	R_w+C_{tr}
Weatherboard (25 mm nominal thickness). Board laps caulked with a durable flexible sealant.	25	70	600mm	1 x 10mm Pbd	75mm 11 kg/m³ GW	39	34
	25	90	600mm	1 x 10mm Pbd	75mm 11 kg/m³ GW	39	34
	25	120	300mm staggered	1 x 10mm Pbd	75mm 11 kg/m³ GW	44	38
	25	70	600mm	2 x 10mm Pbd	75mm 11 kg/m³ GW	41	37
	25	90	600mm	2 x 10mm Pbd	75mm 11 kg/m³ GW	41	37
	25	120	300mm staggered	2 x 10mm Pad	75mm 11 kg/m³ GW	47	42
	25	70	600mm	1 x 13mm Pad	75mm 11 kg/m³ GW	38	34
	25	90	600mm	1 x 13mm Pad	75mm 11 kg/m³ GW	39	35
	25	120	300mm staggered	1 x 13mm Pad	75mm 11 kg/m³ GW	45	39
	25	70	600mm	2 x 13mm Pad	75mm 11 kg/m³ GW	41	38
	25	90	600mm	2 x 13mm Pad	75mm 11 kg/m³ GW	41	38
	25	120	300mm staggered	2 x 13mm Pad	75mm 11 kg/m³ GW	48	43
	25	70	600mm	1 x 16mm FR Pad	75mm 11 kg/m³ GW	39	35
	25	90	600mm	1 x 16mm FR Pad	75mm 11 kg/m³ GW	39	36
	25	120	300mm staggered	1 x 16mm FR Pad	75mm 11 kg/m³ GW	45	41
	Resilient Steel Channel	90	600mm	2 x 16mm FR Pad	75mm 11 kg/m³ GW	50	44

Table 1: R_w and R_w+C_{tr} Ratings Weatherboard Clad Walls

NOTES
1. A 90 mm stud without batten may be used in lieu of and at the same rating as a 70 mm stud with a 25 mm batten.
2. For staggered stud wall frames with 120 mm plates, either 70 or 90 mm studs may be used. See also Section 3.4.

(ii) Chamfer Boards or Shiplap Boards (Hardwood or Softwood) of 19 mm thickness

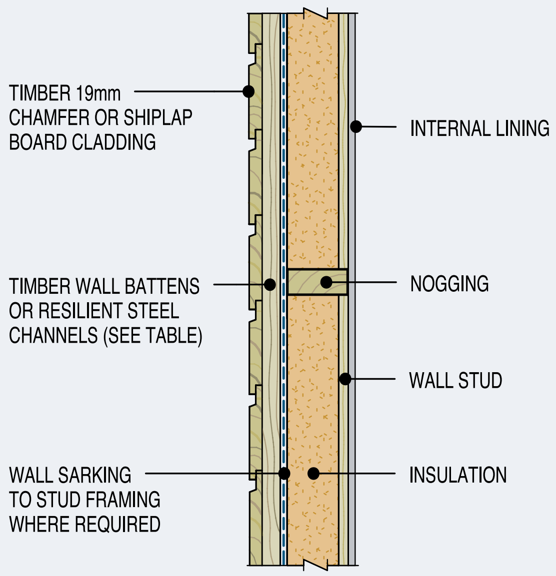


Figure 5: Chamfer Board or Shiplap Board cladding. Vertical section through wall

External Cladding	Batten	Frame	Stud Centres (max)	Internal Lining	Insulation	R_w	$R_w + C_{tr}$
Chamfer Board or Shiplap Boards (19 mm thickness)	25	70	600mm	1 x 10mm Pbd	75mm 11 kg/m³ GW	38	33
	25	90	600mm	1 x 10mm Pbd	75mm 11 kg/m³ GW	38	33
	25	120	300mm staggered	1 x 10mm Pbd	75mm 11 kg/m³ GW	44	38
	25	70	600mm	2 x 10mm Pbd	75mm 11 kg/m³ GW	41	37
	25	90	600mm	2 x 10mm Pbd	75mm 11 kg/m³ GW	41	37
	25	120	300mm staggered	2 x 10mm Pbd	75mm 11 kg/m³ GW	47	42
	25	70	600mm	1 x 13mm Pbd	75mm 11 kg/m³ GW	38	33
	25	90	600mm	1 x 13mm Pbd	75mm 11 kg/m³ GW	39	34
	25	120	300mm staggered	1 x 13mm Pbd	75mm 11 kg/m³ GW	44	39
	25	70	600mm	2 x 13mm Pbd	75mm 11 kg/m³ GW	41	38
	25	90	600mm	2 x 13mm Pbd	75mm 11 kg/m³ GW	41	38
	25	120	300mm staggered	2 x 13mm Pbd	75mm 11 kg/m³ GW	48	43
	25	70	600mm	1 x 16mm FR Pbd	75mm 11 kg/m³ GW	39	35
	25	90	600mm	1 x 16mm FR Pbd	75mm 11 kg/m³ GW	39	36
	25	120	300mm staggered	1 x 16mm FR Pbd	75mm 11 kg/m³ GW	45	40
	Resilient Steel Channel	90	600mm	2 x 16mm FR Pbd	75mm 11 kg/m³ GW	50	44

Table 2: R_w and $R_w + C_{tr}$ Ratings Chamfer Board or Shiplap Clad Walls

NOTES
1. A 90 mm stud without batten may be used in lieu of and at the same rating as a 70 mm stud with a 25 mm batten.
2. For staggered stud wall frames with 120 mm plates, either 70 or 90 mm studs may be used. See also Section 3.4.

(iii) Chamfer Boards or Shiplap Boards (Hardwood or Softwood) of 19 mm thickness over 6 mm Fibre Cement

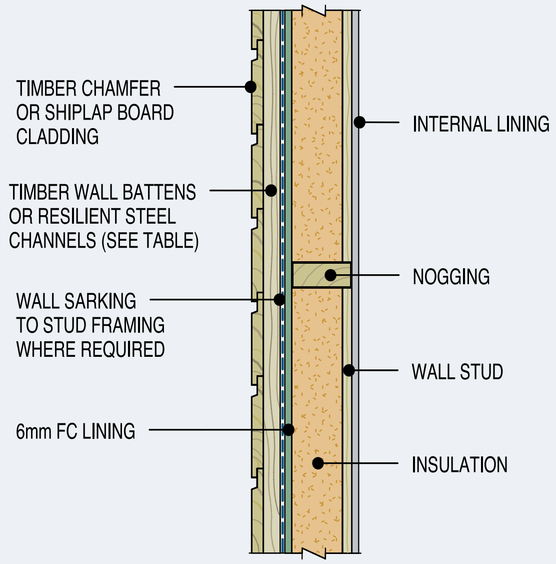


Figure 6: Chamfer Board or Shiplap Board cladding over Fibre Cement. Vertical section through wall

External Cladding	Batten	Frame	Stud Centres (max)	Internal Lining	Insulation	R_w	R_w+C_{tr}
Chamfer Board or Shiplap Boards (19 mm thickness) with 6 mm Fibre Cement behind	25	70	600mm	1 x 10mm Pbd	75mm 11 kg/m³ GW	44	38
	25	90	600mm	1 x 10mm Pbd	75mm 11 kg/m³ GW	44	39
	25	120	300mm staggered	1 x 10mm Pbd	75mm 11 kg/m³ GW	49	43
	25	70	600mm	2 x 10mm Pbd	75mm 11 kg/m³ GW	46	42
	25	90	600mm	2 x 10mm Pbd	75mm 11 kg/m³ GW	46	42
	25	120	300mm staggered	2 x 10mm Pbd	75mm 11 kg/m³ GW	52	47
	25	70	600mm	1 x 13mm Pbd	75mm 11 kg/m³ GW	43	39
	25	90	600mm	1 x 13mm Pbd	75mm 11 kg/m³ GW	43	40
	25	120	300mm staggered	1 x 13mm Pbd	75mm 11 kg/m³ GW	49	44
	25	70	600mm	2 x 13mm Pbd	75mm 11 kg/m³ GW	46	42
	25	90	600mm	2 x 13mm Pbd	75mm 11 kg/m³ GW	46	43
	25	120	300mm staggered	2 x 13mm Pbd	75mm 11 kg/m³ GW	52	48
	25	70	600mm	1 x 16mm FR Pbd	75mm 11 kg/m³ GW	43	40
	25	90	600mm	1 x 16mm FR Pbd	75mm 11 kg/m³ GW	43	40
	25	120	300mm staggered	1 x 16mm FR Pbd	75mm 11 kg/m³ GW	49	45
	Resilient Steel Channel	90	600mm	2 x 16mm FR Pbd	75mm 11 kg/m³ GW	54	48

Table 3: R_w and R_w+C_{tr} Ratings Chamfer or Shiplap Board over 6 mm Fibre Cement clad walls

NOTES
1. A 90 mm stud without batten may be used in lieu of and at the same rating as a 70 mm stud with a 25 mm batten.
2. For staggered stud wall frames with 120 mm plates, either 70 or 90 mm studs may be used. See also Section 3.4.
3. The 6 mm fibre cement board may be located on either the inside or the outside of the batten

(iv) 12 mm Plywood

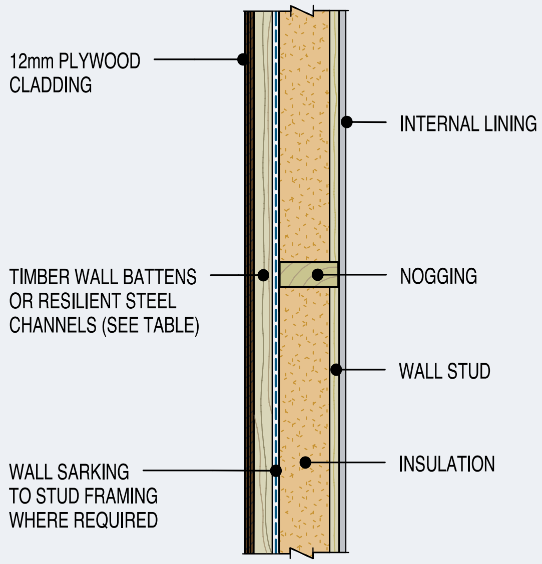


Figure 7: 12 mm Plywood cladding over Fibre Cement. Vertical section through wall

External Cladding	Batten	Frame	Stud Centres (max)	Internal Lining	Insulation	R_w	R_w+C_{tr}
12 mm Plywood	25	70	600mm	1 x 10mm Pbd	75mm 11 kg/m³ GW	37	31
	25	90	600mm	1 x 10mm Pbd	75mm 11 kg/m³ GW	38	33
	25	120	300mm staggered	1 x 10mm Pbd	75mm 11 kg/m³ GW	42	35
	25	70	600mm	2 x 10mm Pbd	75mm 11 kg/m³ GW	41	35
	25	90	600mm	2 x 10mm Pbd	75mm 11 kg/m³ GW	42	37
	25	120	300mm staggered	2 x 10mm Pbd	75mm 11 kg/m³ GW	47	41
	25	70	600mm	1 x 13mm Pbd	75mm 11 kg/m³ GW	38	33
	25	90	600mm	1 x 13mm Pbd	75mm 11 kg/m³ GW	38	33
	25	120	300mm staggered	1 x 13mm Pbd	75mm 11 kg/m³ GW	43	37
	25	70	600mm	2 x 13mm Pbd	75mm 11 kg/m³ GW	42	37
	25	90	600mm	2 x 13mm Pbd	75mm 11 kg/m³ GW	42	38
	25	120	300mm staggered	2 x 13mm Pbd	75mm 11 kg/m³ GW	48	42
	25	70	600mm	1 x 16mm FR Pbd	75mm 11 kg/m³ GW	39	34
	25	90	600mm	1 x 16mm FR Pbd	75mm 11 kg/m³ GW	39	35
	25	120	300mm staggered	1 x 16mm FR Pbd	75mm 11 kg/m³ GW	45	40
	Resilient Steel Channel	90	600mm	2 x 16mm FR Pbd	75mm 11 kg/m³ GW	50	42

Table 4: R_w and R_w+C_{tr} Ratings 12 mm Plywood cladding

NOTES
1. A 90 mm stud without batten may be used in lieu of and at the same rating as a 70 mm stud with a 25 mm batten.
2. For staggered stud wall frames with 120 mm plates, either 70 or 90 mm studs may be used. See also Section 3.4.

(v) 9.5 mm Hardboard Planks

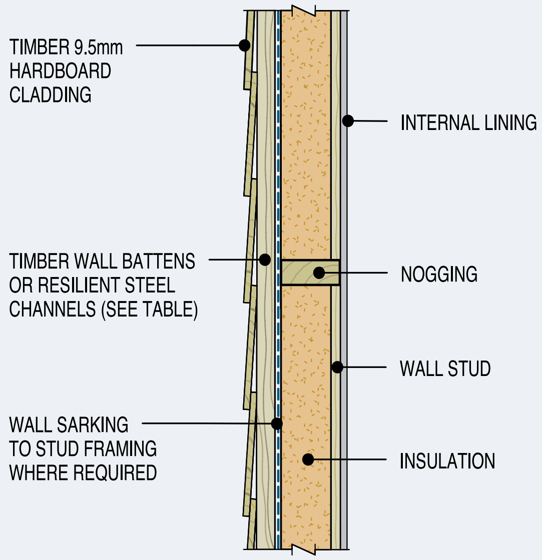


Figure 8: 9.5 mm Hardwood Plank cladding. Vertical section through wall

External Cladding	Batten	Frame	Stud Centres (max)	Internal Lining	Insulation	R_w	R_w+C_{tr}
9.5 mm Hardboard	25	70	600mm	1 x 10mm Pbd	75mm 11 kg/m³ GW	43	35
	25	90	600mm	1 x 10mm Pbd	75mm 11 kg/m³ GW	43	35
	25	120	300mm staggered	1 x 10mm Pbd	75mm 11 kg/m³ GW	47	38
	25	70	600mm	2 x 10mm Pbd	75mm 11 kg/m³ GW	47	39
	25	90	600mm	2 x 10mm Pbd	75mm 11 kg/m³ GW	47	41
	25	120	300mm staggered	2 x 10mm Pbd	75mm 11 kg/m³ GW	52	43
	25	70	600mm	1 x 13mm Pbd	75mm 11 kg/m³ GW	44	35
	25	90	600mm	1 x 13mm Pbd	75mm 11 kg/m³ GW	44	37
	25	120	300mm staggered	1 x 13mm Pbd	75mm 11 kg/m³ GW	49	40
	25	70	600mm	2 x 13mm Pbd	75mm 11 kg/m³ GW	48	41
	25	90	600mm	2 x 13mm Pbd	75mm 11 kg/m³ GW	48	42
	25	120	300mm staggered	2 x 13mm Pbd	75mm 11 kg/m³ GW	53	45
	25	70	600mm	1 x 16mm FR Pbd	75mm 11 kg/m³ GW	45	38
	25	90	600mm	1 x 16mm FR Pbd	75mm 11 kg/m³ GW	45	40
	25	120	300mm staggered	1 x 16mm FR Pbd	75mm 11 kg/m³ GW	50	43
	Resilient Steel Channel	90	600mm	2 x 16mm FR Pbd	75mm 11 kg/m³ GW	55	45

Table 5: R_w and R_w+C_{tr} Ratings 9.5 mm Hardboard Plank cladding

NOTES

1. A 90 mm stud without batten may be used in lieu of and at the same rating as a 70 mm stud with a 25 mm batten.

2. For staggered stud wall frames with 120 mm plates, either 70 or 90 mm studs may be used. See also Section 3.4.

(i) 7.5 mm Fibre Cement Board (11 kg/m²)

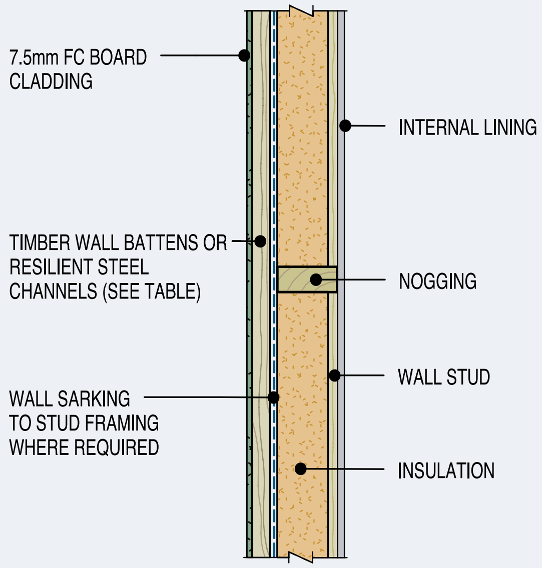


Figure 9: 7.5 mm Fibre Cement Board (11 kg/m2) cladding. Vertical section through wall

External Cladding	Batten	Frame	Stud Centres (max)	Internal Lining	Insulation	R_w	$R_w + C_{tr}$
7.5 mm Fibre cement (12.2 kg/m²) (with acrylic coating	25	70	600mm	1 x 10mm Pbd	75mm 11 kg/m³ GW	44	37
	25	90	600mm	1 x 10mm Pbd	75mm 11 kg/m³ GW	44	37
	25	120	300mm staggered	1 x 10mm Pbd	75mm 11 kg/m³ GW	48	40
	25	70	600mm	2 x 10mm Pbd	75mm 11 kg/m³ GW	47	41
	25	90	600mm	2 x 10mm Pbd	75mm 11 kg/m³ GW	47	41
	25	120	300mm staggered	2 x 10mm Pbd	75mm 11 kg/m³ GW	52	45
	25	70	600mm	1 x 13mm Pbd	75mm 11 kg/m³ GW	44	37
	25	90	600mm	1 x 13mm Pbd	75mm 11 kg/m³ GW	44	38
	25	120	300mm staggered	1 x 13mm Pbd	75mm 11 kg/m³ GW	49	42
	25	70	600mm	2 x 13mm Pbd	75mm 11 kg/m³ GW	48	42
	25	90	600mm	2 x 13mm Pbd	75mm 11 kg/m³ GW	48	43
	25	120	300mm staggered	2 x 13mm Pbd	75mm 11 kg/m³ GW	53	47
	25	70	600mm	1 x 16mm FR Pbd	75mm 11 kg/m³ GW	44	39
	25	90	600mm	1 x 16mm FR Pbd	75mm 11 kg/m³ GW	44	40
	25	120	300mm staggered	1 x 16mm FR Pbd	75mm 11 kg/m³ GW	50	44
	Resilient Steel Channel	90	600mm	2 x 16mm FR Pbd	75mm 11 kg/m³ GW	54	45

Table 6: R_w and $R_w + C_{tr}$ Ratings 7.5 mm Fibre Cement External Cladding

NOTES
1. A 90 mm stud without batten may be used in lieu of and at the same rating as a 70 mm stud with a 25 mm batten.
2. For staggered stud wall frames with 120 mm plates, either 70 or 90 mm studs may be used. See also Section 3.4.

(ii) 7.5 mm Fibre Cement Board over 6mm Fibre Cement (20 kg/m²)

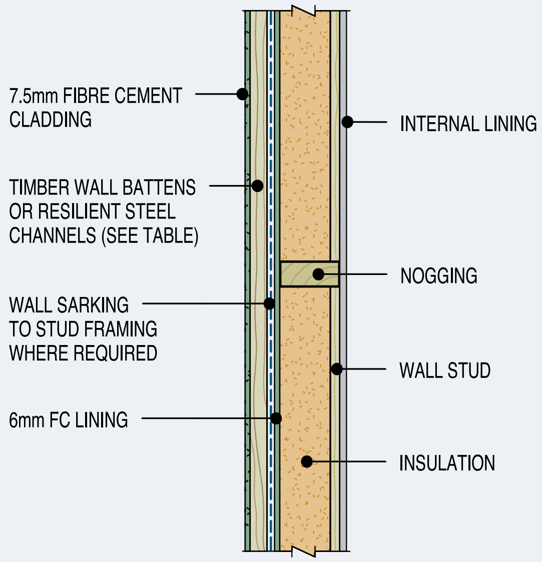


Figure 10: 7.5 mm Fibre Cement Board over 6 mm Fibre Cement cladding. Vertical section through wall

External Cladding	Batten	Frame	Stud Centres (max)	Internal Lining	Insulation	R_w	R_w+C_{tr}
7.5 mm Fibre Cement with 6mm Fibre Cement behind (21.2 kg/m²) (with acrylic coating)	25	70	600mm	1 x 10mm Pbd	75mm 11 kg/m3 GW	47	40
	25	90	600mm	1 x 10mm Pbd	75mm 11 kg/m3 GW	47	41
	25	120	300mm staggered	1 x 10mm Pbd	75mm 11 kg/m3 GW	52	44
	25	70	600mm	2 x 10mm Pbd	75mm 11 kg/m3 GW	50	44
	25	90	600mm	2 x 10mm Pbd	75mm 11 kg/m3 GW	50	45
	25	120	300mm staggered	2 x 10mm Pbd	75mm 11 kg/m3 GW	56	49
	25	70	600mm	1 x 13mm Pbd	75mm 11 kg/m3 GW	47	41
	25	90	600mm	1 x 13mm Pbd	75mm 11 kg/m3 GW	47	42
	25	120	300mm staggered	1 x 13mm Pbd	75mm 11 kg/m3 GW	53	46
	25	70	600mm	2 x 13mm Pbd	75mm 11 kg/m3 GW	50	45
	25	90	600mm	2 x 13mm Pbd	75mm 11 kg/m3 GW	50	46
	25	120	300mm staggered	2 x 13mm Pbd	75mm 11 kg/m3 GW	56	50
	25	70	600mm	1 x 16mm FR Pbd	75mm 11 kg/m3 GW	47	42
	25	90	600mm	1 x 16mm FR Pbd	75mm 11 kg/m3 GW	47	43
	25	120	300mm staggered	1 x 16mm FR Pbd	75mm 11 kg/m3 GW	53	48
	Resilient Steel Channel	90	600mm	2 x 16mm FR Pbd	75mm 11 kg/m3 GW	57	49

Table 7: R_w and R_w+C_{tr} Ratings 7.5 mm Fibre Cement Board over 6 mm Fibre Cement cladding.

NOTES
1. A 90mm stud without batten may be used in lieu of and at the same rating as a 70 mm stud with a 25 mm batten.
2. For staggered stud wall frames with 120 mm plates, either 70 or 90 mm studs may be used. See also Section 3.4.
3. The 6 mm fibre cement board may be located on either the inside or the outside of the batten.

(iii) 9 mm Fibre Cement Cladding

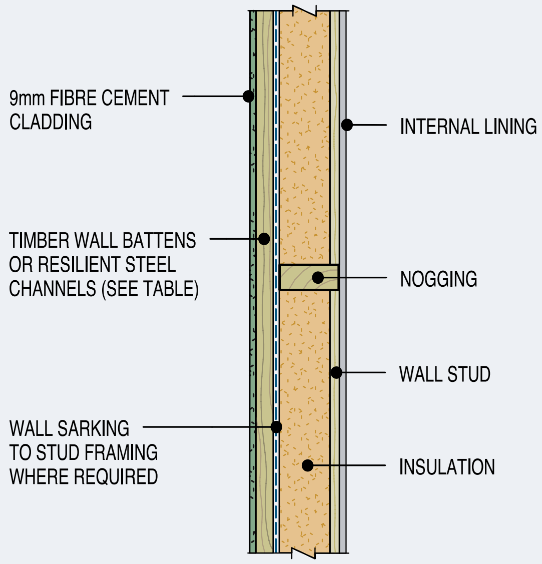


Figure 11: 9 mm Fibre Cement Cladding. Vertical section through wall

External Cladding	Batten	Frame	Stud Centres (max)	Internal Lining	Insulation	R_w	R_w+C_{tr}
9 mm Fibre Cement Cladding (12.2 kg/m²)	25	70	600mm	1 x 10mm Pbd	75mm 11 kg/m3 GW	47	40
	25	90	600mm	1 x 10mm Pbd	75mm 11 kg/m3 GW	47	41
	25	120	300mm staggered	1 x 10mm Pbd	75mm 11 kg/m3 GW	52	44
	25	70	600mm	2 x 10mm Pbd	75mm 11 kg/m3 GW	50	44
	25	90	600mm	2 x 10mm Pbd	75mm 11 kg/m3 GW	50	45
	25	120	300mm staggered	2 x 10mm Pbd	75mm 11 kg/m3 GW	56	49
	25	70	600mm	1 x 13mm Pbd	75mm 11 kg/m3 GW	47	41
	25	90	600mm	1 x 13mm Pbd	75mm 11 kg/m3 GW	47	42
	25	120	300mm staggered	1 x 13mm Pbd	75mm 11 kg/m3 GW	53	46
	25	70	600mm	2 x 13mm Pbd	75mm 11 kg/m3 GW	50	45
	25	90	600mm	2 x 13mm Pbd	75mm 11 kg/m3 GW	50	46
	25	120	300mm staggered	2 x 13mm Pbd	75mm 11 kg/m3 GW	56	50
	25	70	600mm	1 x 16mm FR Pbd	75mm 11 kg/m3 GW	47	42
	25	90	600mm	1 x 16mm FR Pbd	75mm 11 kg/m3 GW	47	43
	25	120	300mm staggered	1 x 16mm FR Pbd	75mm 11 kg/m3 GW	53	48
	Resilient Steel Channel	90	600mm	2 x 16mm FR Pbd	75mm 11 kg/m3 GW	57	49

Table 8: R_w and R_w+C_{tr} Ratings 9 mm Fibre Cement Cladding

NOTES
1. A 90 mm stud without batten may be used in lieu of and at the same rating as a 70 mm stud with a 25 mm batten.
2. For staggered stud wall frames with 120 mm plates, either 70 or 90 mm studs may be used. See also Section 3.4.

(iv) 11 mm Fibre Cement Weatherboards

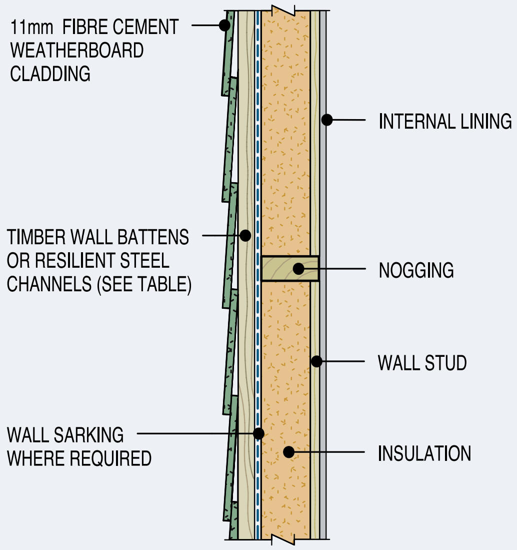


Figure 12: 11 mm Fibre Cement Cladding. Vertical section through wall

External Cladding	Batten	Frame	Stud Centres (max)	Internal Lining	Insulation	R_w	R_w+C_{tr}
11 mm Fibre Cement Weatherboards (17.3 kg/m²)	25	70	600mm	1 x 10mm Pbd	75mm 11 kg/m³ GW	43	35
	25	90	600mm	1 x 10mm Pbd	75mm 11 kg/m³ GW	43	35
	25	120	300mm staggered	1 x 10mm Pbd	75mm 11 kg/m³ GW	47	39
	25	70	600mm	2 x 10mm Pbd	75mm 11 kg/m³ GW	46	39
	25	90	600mm	2 x 10mm Pbd	75mm 11 kg/m³ GW	47	41
	25	120	300mm staggered	2 x 10mm Pbd	75mm 11 kg/m³ GW	52	44
	25	70	600mm	1 x 13mm Pbd	75mm 11 kg/m³ GW	43	35
	25	90	600mm	1 x 13mm Pbd	75mm 11 kg/m³ GW	43	37
	25	120	300mm staggered	1 x 13mm Pbd	75mm 11 kg/m³ GW	48	40
	25	70	600mm	2 x 13mm Pbd	75mm 11 kg/m³ GW	47	41
	25	90	600mm	2 x 13mm Pbd	75mm 11 kg/m³ GW	48	42
	25	120	300mm staggered	2 x 13mm Pbd	75mm 11 kg/m³ GW	53	46
	25	70	600mm	1 x 16mm FR Pbd	75mm 11 kg/m³ GW	44	38
	25	90	600mm	1 x 16mm FR Pbd	75mm 11 kg/m³ GW	44	39
	25	120	300mm staggered	1 x 16mm FR Pbd	75mm 11 kg/m³ GW	49	43
	Resilient Steel Channel	90	600mm	2 x 16mm FR Pbd	75mm 11 kg/m³ GW	55	48

Table 9: R_w and R_w+C_{tr} Ratings 11 mm Fibre Cement Cladding

NOTES
1. A 90 mm stud without batten may be used in lieu of and at the same rating as a 70 mm stud with a 25 mm batten.
2. For staggered stud wall frames with 120 mm plates, either 70 or 90 mm studs may be used. See also Section 3.4.

(v) 11 mm Fibre Cement Weatherboards over 6 mm Fibre Cement

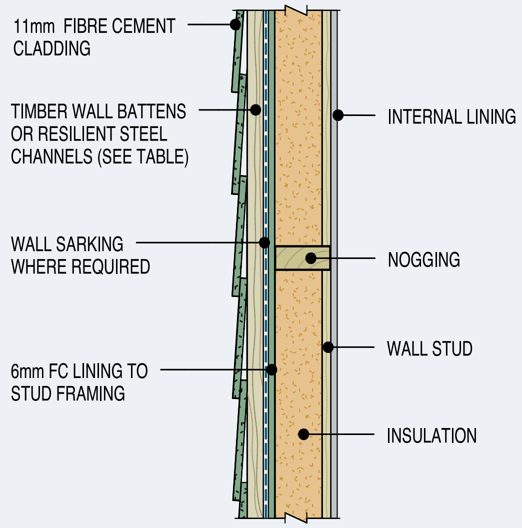


Figure 13: 11 mm Fibre Cement over 6 mm Fibre Cement Cladding. Vertical section through wall

External Cladding	Batten	Frame	Stud Centres (max)	Internal Lining	Insulation	R_w	R_w+C_{tr}
11 mm Fibre Cement Weatherboards with 6 mm Fibre Cement behind (17.3 kg/m²)	25	70	600 mm	1 x 10 mm Pbd	75 mm 11 kg/m³ GW	47	39
	25	90	600 mm	1 x 10 mm Pbd	75 mm 11 kg/m³ GW	47	41
	25	120	300 mm staggered	1 x 10 mm Pbd	75 mm 11 kg/m³ GW	52	44
	25	70	600 mm	2 x 10 mm Pbd	75 mm 11 kg/m³ GW	50	44
	25	90	600 mm	2 x 10 mm Pbd	75 mm 11 kg/m³ GW	50	45
	25	120	300 mm staggered	2 x 10 mm Pbd	75 mm 11 kg/m³ GW	56	49
	25	70	600 mm	1 x 13 mm Pbd	75 mm 11 kg/m³ GW	47	41
	25	90	600 mm	1 x 13 mm Pbd	75 mm 11 kg/m³ GW	47	42
	25	120	300 mm staggered	1 x 13 mm Pbd	75 mm 11 kg/m³ GW	53	45
	25	70	600 mm	2 x 13 mm Pbd	75 mm 11 kg/m³ GW	50	45
	25	90	600 mm	2 x 13 mm Pbd	75 mm 11 kg/m³ GW	50	46
	25	120	300 mm staggered	2 x 13 mm Pbd	75 mm 11 kg/m³ GW	56	50
	25	70	600 mm	1 x 16 mm FR Pbd	75 mm 11 kg/m³ GW	47	42
	25	90	600 mm	1 x 16 mm FR Pbd	75 mm 11 kg/m³ GW	47	43
	25	120	300 mm staggered	1 x 16 mm FR Pbd	75 mm 11 kg/m³ GW	53	47
	Resilient Steel Channel	90	600mm	2 x 16 mm FR Pbd	75 mm 11 kg/m³ GW	57	51

***Table 10: R_w and R_w+C_{tr} Ratings 11 mm Fibre Cement Cladding* over 6 mm Fibre Cement**

NOTES
1. A 90 mm stud without batten may be used in lieu of and at the same rating as a 70 mm stud with a 25 mm batten.
2. For staggered stud wall frames with 120 mm plates, either 70 or 90 mm studs may be used. See also Section 3.4.
3. The 6 mm fibre cement board may be located on either the inside or the outside of the batten.
.

(vi) 16mm Fibre Cement Weatherboards

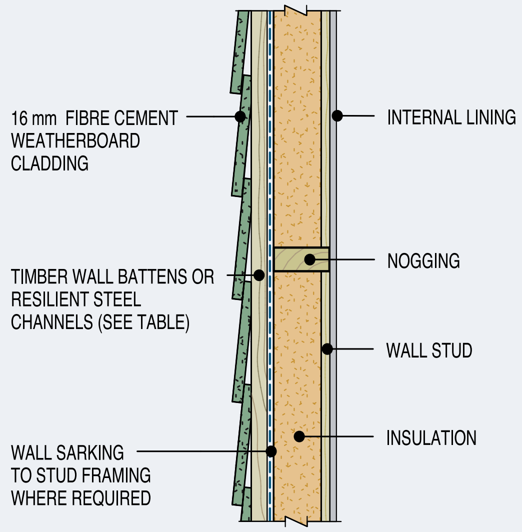


Figure 14: 16 mm Fibre Cement Cladding. Vertical section through wall

External Cladding	Batten	Frame	Stud Centres (max)	Internal Lining	Insulation	R_w	$R_w + C_{tr}$
16 mm Fibre Cement Weatherboards (18.4 kg/m²)	25	70	600 mm	1 x 10 mm Pbd	75 mm 11 kg/m³ GW	44	39
	25	90	600 mm	1 x 10 mm Pbd	75 mm 11 kg/m³ GW	45	40
	25	120	300 mm staggered	1 x 10 mm Pbd	75 mm 11 kg/m³ GW	50	43
	25	70	600 mm	2 x 10 mm Pbd	75 mm 11 kg/m³ GW	47	42
	25	90	600 mm	2 x 10 mm Pbd	75 mm 11 kg/m³ GW	47	43
	25	120	300 mm staggered	2 x 10 mm Pbd	75 mm 11 kg/m³ GW	53	48
	25	70	600 mm	1 x 13 mm Pbd	75 mm 11 kg/m³ GW	44	40
	25	90	600 mm	1 x 13 mm Pbd	75 mm 11 kg/m³ GW	44	40
	25	120	300 mm staggered	1 x 13 mm Pbd	75 mm 11 kg/m³ GW	50	45
	25	70	600 mm	2 x 13 mm Pbd	75 mm 11 kg/m³ GW	47	43
	25	90	600 mm	2 x 13 mm Pbd	75 mm 11 kg/m³ GW	47	44
	25	120	300 mm staggered	2 x 13 mm Pbd	75 mm 11 kg/m³ GW	53	49
	25	70	600 mm	1 x 16 mm FR Pbd	75 mm 11 kg/m³ GW	44	40
	25	90	600 mm	1 x 16 mm FR Pbd	75 mm 11 kg/m³ GW	44	41
	25	120	300 mm staggered	1 x 16 mm FR Pbd	75 mm 11 kg/m³ GW	50	46
	Resilient Steel Channel	90	600 mm	2 x 16 mm FR Pbd	75 mm 11 kg/m³ GW	55	49

Table 11: R_w and $R_w + C_{tr}$ Ratings 16 mm Fibre Cement Cladding

NOTES
1. A 90 mm stud without batten may be used in lieu of and at the same rating as a 70 mm stud with a 25 mm batten.
2. For staggered stud wall frames with 120 mm plates, either 70 or 90 mm studs may be used. See also Section 3.4.

3.6.3 Metal External Cladding

(i) Corrugated (regular) horizontal or vertical metal cladding on battens

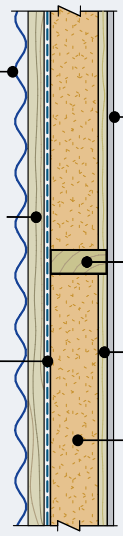


Figure 15: Metal External Cladding. Vertical section through wall

External Cladding	Batten	Frame	Stud Centres (max)	Internal Lining	Insulation	R_w	$R_w + C_{tr}$
Corrugated (regular) metal cladding on battens with sarking (0.42mm BMT)	25	70	600 mm	1 x 10 mm Pbd	75 mm 11 kg/m³ GW	38	29
	25	90	600 mm	1 x 10 mm Pbd	75 mm 11 kg/m³ GW	39	30
	25	120	300 mm staggered	1 x 10 mm Pbd	75 mm 11 kg/m³ GW	41	31
	25	70	600 mm	2 x 10 mm Pbd	75 mm 11 kg/m³ GW	43	34
	25	90	600 mm	2 x 10 mm Pbd	75 mm 11 kg/m³ GW	44	35
	25	120	300 mm staggered	2 x 10 mm Pbd	75 mm 11 kg/m³ GW	47	38
	25	70	600 mm	1 x 13 mm Pbd	75 mm 11 kg/m³ GW	40	30
	25	90	600 mm	1 x 13 mm Pbd	75 mm 11 kg/m³ GW	41	31
	25	120	300 mm staggered	1 x 13 mm Pbd	75 mm 11 kg/m³ GW	43	34
	25	70	600 mm	2 x 13 mm Pbd	75 mm 11 kg/m³ GW	45	35
	25	90	600 mm	2 x 13 mm Pbd	75 mm 11 kg/m³ GW	46	37
	25	120	300 mm staggered	2 x 13 mm Pbd	75 mm 11 kg/m³ GW	47	40
	25	70	600 mm	1 x 16 mm FR Pbd	75 mm 11 kg/m³ GW	42	33
	25	90	600 mm	1 x 16 mm FR Pbd	75 mm 11 kg/m³ GW	42	34
	25	120	300 mm staggered	1 x 16 mm FR Pbd	75 mm 11 kg/mv GW	45	37
	Resilient Steel Channel	90	600 mm	2 x 16 mm FR Pbd	75 mm 11 kg/m³ GW	50	41

Table 12: R_w and $R_w + C_{tr}$ Ratings Metal External Cladding

NOTES
1.A 90 mm stud without batten may be used in lieu of and at the same rating as a 70 mm stud with a 25 mm batten.
2. For staggered stud wall frames with 120 mm plates, either 70 or 90 mm studs may be used. See also Section 3.4.

(i) Corrugated (mini) horizontal or vertical metal cladding on battens

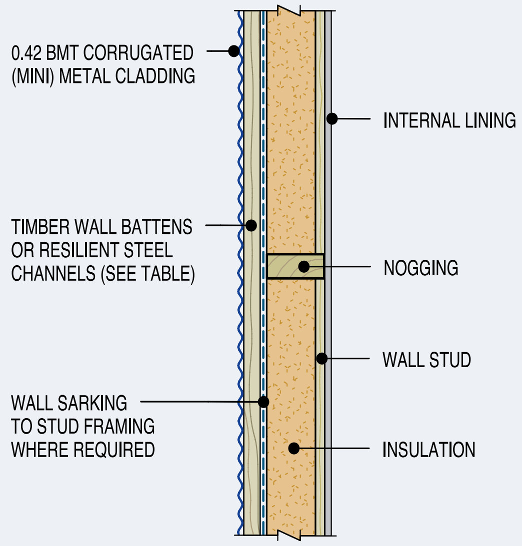


Figure 16: Metal External Cladding. Vertical section through wall

External Cladding	Batten	Frame	Stud Centres (max)	Internal Lining	Insulation	R_w	R_w+C_{tr}
Corrugated (mini) metal cladding on battens with sarking (0.42 mm BMT)	25	70	600 mm	1 x 10 mm Pbd	75 mm 11 kg/m³ GW	38	29
	25	90	600 mm	1 x 10 mm Pbd	75 mm 11 kg/m³ GW	39	30
	25	120	300 mm staggered	1 x 10 mm Pbd	75 mm 11 kg/m³ GW	41	31
	25	70	600 mm	2 x 10 mm Pbd	75 mm 11 kg/m³ GW	44	34
	25	90	600 mm	2 x 10 mm Pbd	75 mm 11 kg/m³ GW	45	35
	25	120	300 mm staggered	2 x 10 mm Pbd	75 mm 11 kg/m³ GW	47	38
	25	70	600 mm	1 x 13 mm Pbd	75 mm 11 kg/m³ GW	40	30
	25	90	600 mm	1 x 13 mm Pbd	75 mm 11 kg/m³ GW	41	31
	25	120	300 mm staggered	1 x 13 mm Pbd	75 mm 11 kg/m³ GW	43	34
	25	70	600 mm	2 x 13 mm Pbd	75 mm 11 kg/m³ GW	45	35
	25	90	600 mm	2 x 13 mm Pbd	75 mm 11 kg/m³ GW	47	37
	25	120	300 mm staggered	2 x 13 mm Pbd	75 mm 11 kg/m³ GW	49	40
	25	70	600 mm	1 x 16 mm FR Pbd	75 mm 11 kg/m³ GW	42	33
	25	90	600 mm	1 x 16 mm FR Pbd	75 mm 11 kg/m³ GW	42	34
	25	120	300 mm staggered	1 x 16 mm FR Pbd	75 mm 11 kg/m³ GW	46	37
	Resilient Steel Channel	90	600 mm	2 x 16 mm FR Pbd	75 mm 11 kg/m³ GW	50	41

Table 13: R_w and R_w+C_{tr} Ratings, Corrugated (mini) horizontal or vertical metal cladding

NOTES
1. A 90 mm stud without batten may be used in lieu of and at the same rating as a 70 mm stud with a 25 mm batten.
2. For staggered stud wall frames with 120 mm plates, either 70 or 90 mm studs may be used. See also Section 3.4.

3.6.4 Brick Veneer

(i) Brick Veneer (90 mm or thicker bricks)

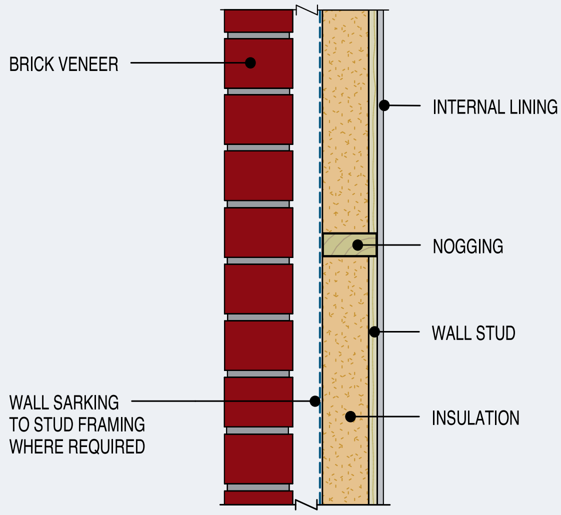


Figure 17: Brick Veneer. Vertical section through wall

External Cladding	Frame	Stud Centres (max)	Internal Lining	Insulation	R_w	$R_w + C_{tr}$
Brick Veneer (hollow or solid) with 90 mm+ Bricks	70	≥450 mm	1 x 10 mm Pbd	75 mm 11 kg/m3 GW	55	51
	90	≥450 mm	1 x 10 mm Pbd	75 mm 11 kg/m3 GW	55	51
	70	≥450 mm	2 x 10 mm Pbd	75 mm 11 kg/m3 GW	56	52
	90	≥450 mm	2 x 10 mm Pbd	75 mm 11 kg/m3 GW	56	52
	70	≥450 mm	1 x 13 mm Pbd	75 mm 11 kg/m3 GW	55	50
	90	≥450 mm	1 x 13 mm Pbd	75 mm 11 kg/m3 GW	55	51
	70	≥450 mm	2 x 13 mm Pbd	75 mm 11 kg/m3 GW	55	51
	90	≥450 mm	2 x 13 mm Pbd	75 mm 11 kg/m3 GW	55	51
	70	≥450 mm	1 x 16 mm FR Pbd	75 mm 11 kg/m3 GW	53	50
	90	≥450 mm	1 x 16 mm FR Pbd	75 mm 11 kg/m3 GW	55	52

Table 14: R_w and $R_w + C_{tr}$ Ratings Brick Veneer

NOTES
1. A 90 mm stud without batten may be used in lieu of and at the same rating as a 70 mm stud with a 25 mm batten.
2. The minimum cavity gap shall be 20 mm

3.7.1 Trussed or Pitched Roofs

(i) Trussed or Pitched Roof with R 3.0 Insulation

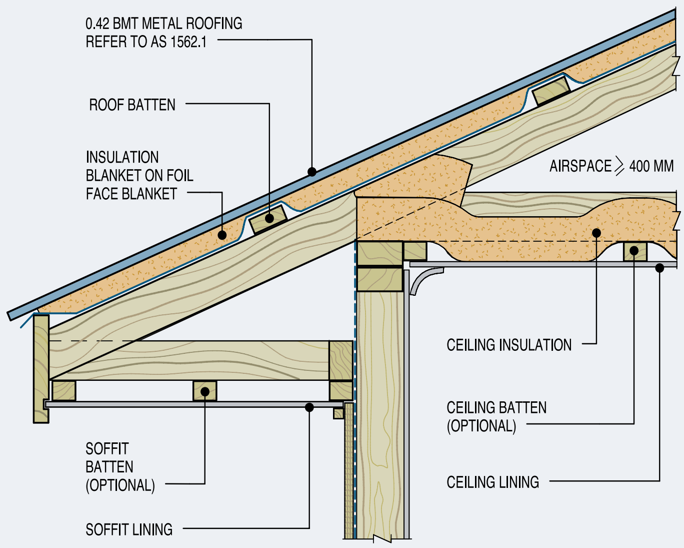


Figure 18: Pitched 0.42mm BMT Corrugated roof with R 3.0 Insulation. Section through roof

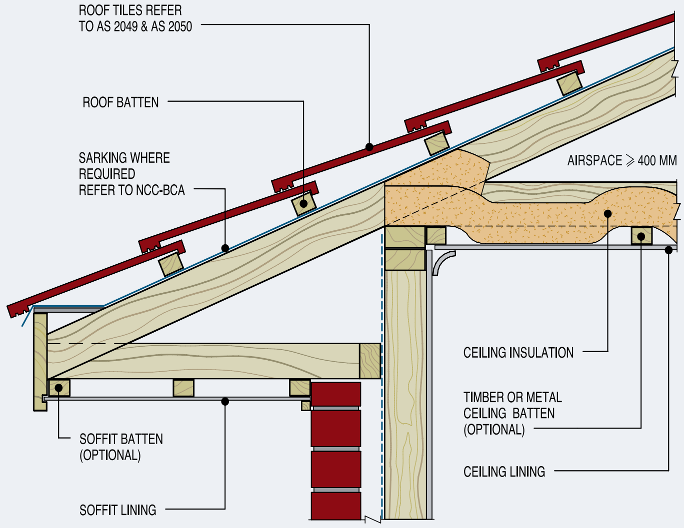
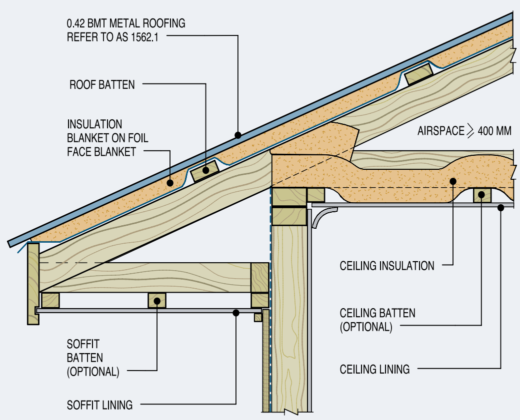


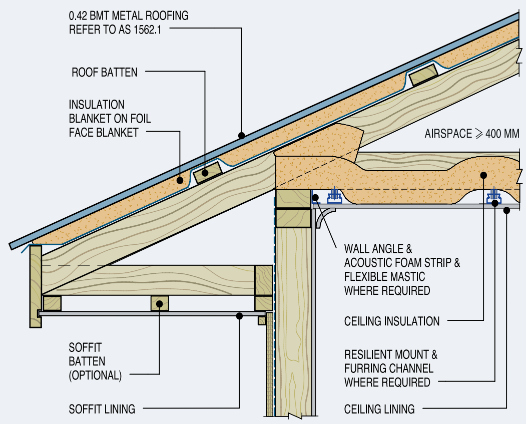
Figure 19: Pitched tiled roof with R 3.0 Insulation. Section through roof

Roof Material	Frame	Truss/rafter Spacing	Ceiling Lining	Insulation	R_w	R_w+C_{tr}
Pitched 0.42 mm BMT Corrugated roof sheeting with 50 mm glasswool insulation bonded to foil	Timber Truss/ rafter with average airspace ≥400 mm	600 mm or greater centres	1 x 10 mm Pbd (ceiling grade)	R 3.0 - 7 kg/m³ GW	42	36
			2 x 10 mm Pbd (ceiling grade)	R 3.0 - 7 kg/m³ GW	48	42
			1 x 13 mm Pbd	R 3.0 - 7 kg/m³ GW	44	38
			2 x 13 mm Pbd	R 3.0 - 7 kg/m³ GW	50	43
			1 x 16 mm FR Pbd	R 3.0 - 7 kg/m³ GW	46	40
Pitched tiled roof with or without sarking			1 x 10 mm Pbd (ceiling grade)	R 3.0 - 7 kg/m³ GW	40	35
			2 x 10 mm Pbd (ceiling grade)	R 3.0 - 7 kg/m³ GW	50	45
			1 x 13 mm Pbd	R 3.0 - 7 kg/m³ GW	43	38
			2 x 13 mm Pbd	R 3.0 - 7 kg/m³ GW	49	43
			1 x FR Pbd	R 3.0 - 7 kg/m³ GW	46	41

Table 15: R_w and R_w+C_{tr} Ratings, Trussed or Pitched Roofs with R 3.0 Insulation

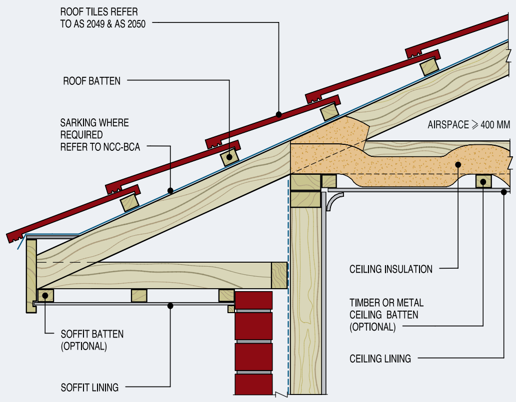
(ii) Trussed or Pitched Roof with R 4.0 Insulation

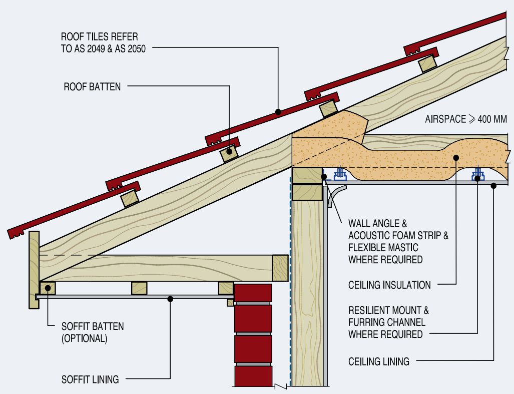




Left: Figure 20: Pitched 0.42mm BMT Corrugated roof with R 4.0 Insulation. Section through roof

RIght: Figure 21: As per FIgure 20 but with resilient mounts and furring channels. Section through roof





Left: Figure 22: Pitched tiled roof with R 4.0 Insulation. Section through roof

Right: Figure 23: As per FIgure 22 but with resilient mounts and furring channels. Section through roof

Roof Material	Frame	Stud Layout	Ceiling Lining	Insulation	R_w	$R_w + C_{tr}$
Pitched 0.42 mm BMT Corrugated roof sheeting with 50 mm glasswool insulation bonded to foil	Timber Truss/ rafter with average airspace ≥400 mm	600 mm or greater centres	1 x 10 mm Pbd (ceiling grade)	R 4.0 - 7 kg/m³ GW	43	37
			2 x 10 mm Pbd (ceiling grade)	R 4.0 - 7 kg/m³ GW	49	43
			1 x 13 mm Pbd	R 4.0 - 7 kg/m³ GW	45	39
			2 x 13 mm Pbd	R 4.0 - 7 kg/m³ GW	51	44
			1 x 16 mm FR Pbd	R 4.0 - 7 kg/m³ GW	47	41
			2 x 13mm Pbd on resilient mounts & furring channels	R 4.0 - 7 kg/m³ GW	52	45
Pitched tiled roof with or without sarking			1 x 10 mm Pbd (ceiling grade)	R 4.0 - 7 kg/m³ GW	40	36
			2 x 10 mm Pbd (ceiling grade)	R 4.0 - 7 kg/m³ GW	50	46
			1 x 13 mm Pbd	R 4.0 - 7 kg/m³ GW	43	39
			2 x 13 mm Pbd	R 4.0 - 7 kg/m³ GW	49	44
			1 x FR Pbd	R 4.0 - 7 kg/m³ GW	46	42
			2 x 13mm Pbd on resilient mounts & furring channels	R 4.0 - 7 kg/m³ GW	51	45

Table 16: R_w and $R_w + C_{tr}$ Ratings, Trussed or Pitched Roofs with R 4.0 Insulation

3.7.2 Cathedral Roof/Ceiling Construction

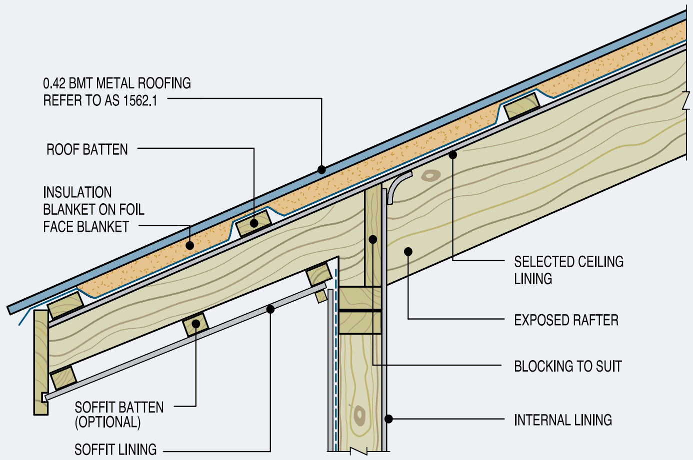


Figure 24: Cathedral Roof/Ceiling Construction. Section through roof

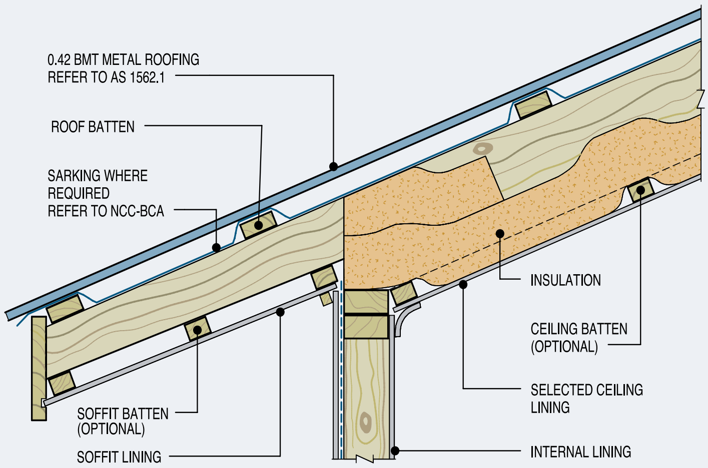


Figure 25: Cathedral Roof/Ceiling Construction. Section through roof

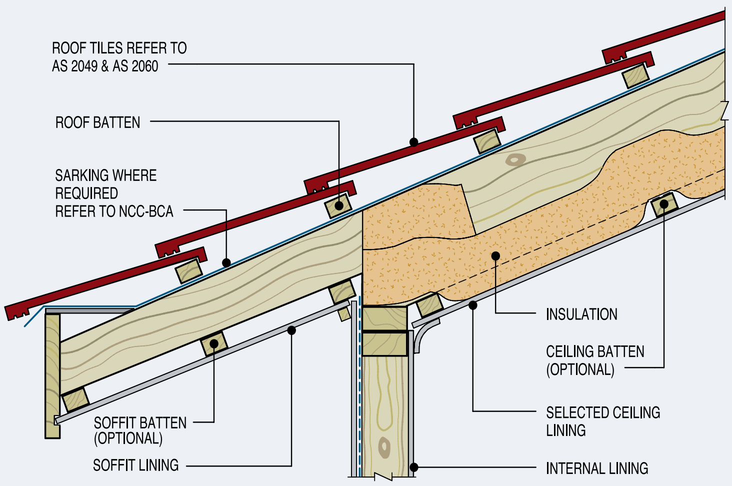


Figure 26: Cathedral Roof/Ceiling Construction. Section through roof

Roof Material	Cavity	Rafter Layout	Ceiling Lining	Insulation	R_w	$R_w + C_{tr}$
Pitched 0.42 mm BMT corrugated roof sheeting with 50mm glasswool insulation bonded to foil or Pitched tiled roof with sarking	**35 mm roof battens with exposed rafters.**	**400 mm Centres**	1 x 10 mm Pbd	Insulation/foil over battens only	32	25
			2 x 10 mm Pbd	Insulation/foil over battens only	38	30
			1 x 13 mm Pbd	Insulation/foil over battens only	34	27
			2 x 13 mm Pbd	Insulation/foil over battens only	40	32
			1 x 16 mm FR Pbd	Insulation/foil over battens only	37	29
		600 mm or greater Centres	1 x 10 mm Pbd	Insulation/foil over battens only	33	25
			2 x 10 mm Pbd	Insulation/foil over battens only	38	30
			1 x 13 mm Pbd	Insulation/foil over battens only	34	27
			2 x 13 mm Pbd	Insulation/foil over battens only	40	32
			1 x 16 mm FR Pbd	Insulation/foil over battens only	37	29
	90 mm	**400 mm Centres**	1 x 10 mm Pbd	75 mm 11 kg/m³ GW	36	27
			2 x 10 mm Pbd	75 mm 11 kg/m³ GW	41	32
			1 x 13 mm Pbd	75 mm 11 kg/m³ GW	38	28
			2 x 13 mm Pbd	75 mm 11 kg/m³ GW	44	34
			1 x 16 mm FR Pbd	75 mm 11 kg/m³ GW	39	31
		600 mm or greater Centres	1 x 10 mm Pbd	75 mm 11 kg/m³ GW	36	27
			2 x 10 mm Pbd	75 mm 11 kg/m³ GW	41	32
			1 x 13 mm Pbd	75 mm 11 kg/m³ GW	38	29
			2 x 13 mm Pbd	75 mm 11 kg/m³ GW	44	34
			1 x 16 mm FR Pbd	75 mm 11 kg/m³ GW	40	31
	140 mm	**400 mm Centres**	1 x 10 mm Pbd	75 mm 11 kg/m³ GW	38	30
			2 x 10 mm Pbd	75 mm 11 kg/m³ GW	44	36
			1 x 13 mm Pbd	75 mm 11 kg/m³ GW	40	32
			2 x 13 mm Pbd	75 mm 11 kg/m³ GW	46	39
			1 x 16 mm FR Pbd	75 mm 11 kg/m³ GW	42	35
		600mm or greater Centres	1 x 10 mm Pbd	75 mm 11 kg/m³ GW	39	30
			2 x 10 mm Pbd	75 mm 11 kg/m³ GW	44	37
			1 x 13 mm Pbd	75 mm 11 kg/m³ GW	41	33
			2 x 13 mm Pbd	75 mm 11 kg/m³ GW	47	39
			1 x 16 mm FR Pbd	75 mm 11 kg/m³ GW	43	36

Table 17: R_w and $R_w + C_{tr}$ Ratings, Cathedral Roof/Ceiling Construction

Roof Material	Cavity	Rafter Layout	Ceiling Lining	Insulation	R_w	$R_w + C_{tr}$
Pitched 0.42 mm BMT corrugated roof sheeting with 50mm glasswool insulation bonded to foil or Pitched tiled roof with sarking	**190 mm**	**400 mm Centres**	1 x 10 mm Pbd	75 mm 11 kg/m³ GW	39	31
			2 x 10 mm Pbd	75 mm 11 kg/m³ GW	44	37
			1 x 13 mm Pbd	75 mm 11 kg/m³ GW	41	33
			2 x 13 mm Pbd	75 mm 11 kg/m³ GW	46	39
			1 x 16 mm FR Pbd	75 mm 11 kg/m³ GW	42	36
		600 mm or greater Centres	1 x 10 mm Pbd	75 mm 11 kg/m³ GW	40	31
			2 x 10 mm Pbd	75 mm 11 kg/m³ GW	45	37
			1 x 13 mm Pbd	75 mm 11 kg/m³ GW	42	33
			2 x 13 mm Pbd	75 mm 11 kg/m³ GW	47	40
			1 x 16 mm FR Pbd	75 mm 11 kg/m³ GW	43	36
	240 mm	**400 mm Centres**	1 x 10 mm Pbd	75 mm 11 kg/m³ GW	40	33
			2 x 10 mm Pbd	75 mm 11 kg/m³ GW	45	39
			1 x 13 mm Pbd	75 mm 11 kg/m³ GW	42	35
			2 x 13 mm Pbd	75 mm 11 kg/m³ GW	47	41
			1 x 16 mm FR Pbd	75 mm 11 kg/m³ GW	43	38
		600 mm or greater Centres	1 x 10 mm Pbd	75 mm 11 kg/m³ GW	40	33
			2 x 10 mm Pbd	75 mm 11 kg/m³ GW	46	39
			1 x 13 mm Pbd	75 mm 11 kg/m³ GW	42	35
			2 x 13 mm Pbd	75 mm 11 kg/m³ GW	48	41
			1 x 16 mm FR Pbd	75 mm 11 kg/m³ GW	44	38

Table 17 (continued): R_w and $R_w + C_{tr}$ Ratings, Cathedral Roof/Ceiling Construction

3.8 Floor Systems – Unenclosed

(i) 19 mm T&G Hardwood flooring or particleboard to top of joists

For improved ratings, of up to 15 dB, for enclosed sub-floors, refer to Section 3.4.

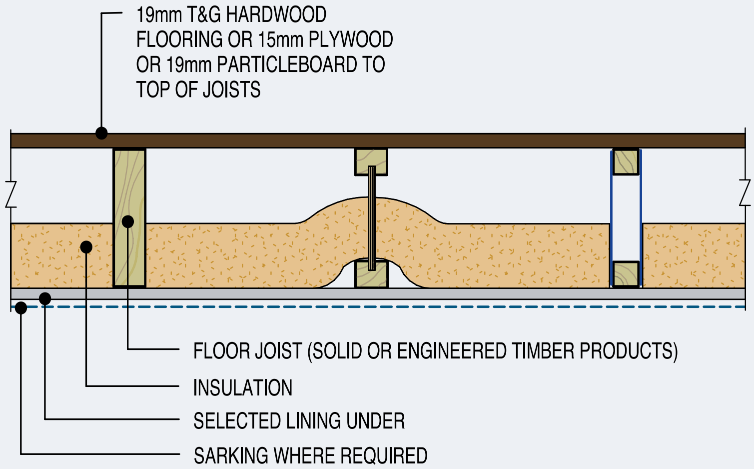


Figure 27: 19 mm T&G Hardwood flooring or particleboard to top of joists

Floor Material	Joist depth (mm)	Joist Layout	Lining to Underside	Insulation	R_w	R_w+C_{tr}
19mm solid T&G Hardwood or Particleboard to top of joists	90 mm	400/450 mm Centres	Nil	Nil	30	27
			Nil	75mm 11 kg/m3 GW	33	29
			1 x 10mm Pbd	75mm 11 kg/m3 GW	40	35
			2 x 10mm Pbd	75mm 11 kg/m3 GW	43	39
			1 x 13mm Pbd	75mm 11 kg/m3 GW	40	36
			2 x 13mm Pbd	75mm 11 kg/m3 GW	43	39
			1 x 16mm Fyrcheck Pbd	75mm 11 kg/m3 GW	40	37
		600 mm Centres	Nil	Nil	30	27
			Nil	75mm 11 kg/m3 GW	33	29
			1 x 10mm Pbd	75mm 11 kg/m3 GW	42	36
			2 x 10mm Pbd	75mm 11 kg/m3 GW	44	40
			1 x 13mm Pbd	75mm 11 kg/m3 GW	42	37
			2 x 13mm Pbd	75mm 11 kg/m3 GW	44	41
			1 x 16mm Fyrcheck Pbd	75mm 11 kg/m3 GW	43	39
	190 mm	400/450 mm Centres	Nil	Nil	30	27
			Nil	75mm 11 kg/m3 GW	34	29
			1 x 10mm Pbd	75mm 11 kg/m3 GW	41	37
			2 x 10mm Pbd	75mm 11 kg/m3 GW	43	40
			1 x 13mm Pbd	75mm 11 kg/m3 GW	40	37
			2 x 13mm Pbd	75mm 11 kg/m3 GW	43	40
			1 x 16mm Fyrcheck Pbd	75mm 11 kg/m3 GW	40	37
		600 mm Centres	Nil	Nil	30	27
			Nil	75mm 11 kg/m3 GW	34	29
			1 x 10mm Pbd	75mm 11 kg/m3 GW	42	39
			2 x 10mm Pbd	75mm 11 kg/m3 GW	44	41
			1 x 13mm Pbd	75mm 11 kg/m3 GW	42	39
			2 x 13mm Pbd	75mm 11 kg/m3 GW	45	42
			1 x 16mm Fyrcheck Pbd	75mm 11 kg/m3 GW	42	39
	290 mm	400/450 mm Centres	Nil	Nil	30	27
			Nil	75mm 11 kg/m3 GW	36	30
			1 x 10mm Pbd	75mm 11 kg/m3 GW	41	38
			2 x 10mm Pbd	75mm 11 kg/m3 GW	43	40
			1 x 13mm Pbd	75mm 11 kg/m3 GW	40	38
			2 x 13mm Pbd	75mm 11 kg/m3 GW	43	40
			1 x 16mm Fyrcheck Pbd	75mm 11 kg/m3 GW	40	37
		600 mm Centres	Nil	Nil	30	27
			Nil	75mm 11 kg/m3 GW	36	30
			1 x 10mm Pbd	75mm 11 kg/m3 GW	42	39
			2 x 10mm Pbd	75mm 11 kg/m3 GW	44	42
			1 x 13mm Pbd	75mm 11 kg/m3 GW	42	39
			2 x 13mm Pbd	75mm 11 kg/m3 GW	44	42
			1 x 16mm Fyrcheck Pbd	75mm 11 kg/m3 GW	42	39

Table 18: R_w and R_w+C_{tr} Ratings, 19 mm T&G Hardwood flooring or particleboard to top of joists

(ii) 19mm T&G Hardwood flooring over 15mm plywood or 19mm particleboard to top of joists

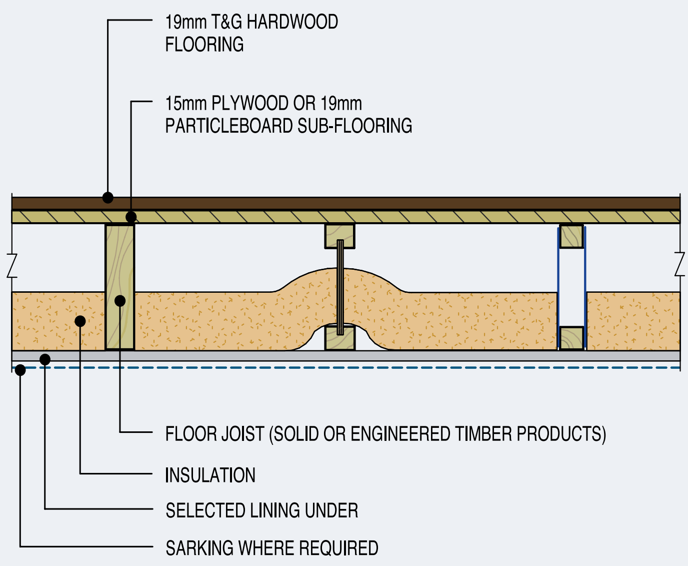


Figure 28: 19mm T&G Hardwood flooring over 15mm plywood or 19mm particleboard to top of joists

Floor Material	Joist depth (mm)	Joist Layout	Lining to Underside	Insulation	R_w	R_w+C_{tr}
19 mm T&G flooring[1] over 15 mm plywood or 19 mm particleboard	90 mm	400/450 mm Centres	Nil	Nil	36	33
			Nil	75 mm 11 kg/m³ GW	38	34
			1 x 10 mm Pbd	75 mm 11 kg/m³ GW	45	41
			2 x 10 mm Pbd	75 mm 11 kg/m³ GW	47	43
			1 x 13 mm Pbd	75 mm 11 kg/m³ GW	45	41
			2 x 13 mm Pbd	75 mm 11 kg/m³ GW	46	43
			1 x 16mm Fyrcheck Pbd	75 mm 11 kg/m³ GW	44	41
		600 mm Centres	Nil	Nil	36	33
			Nil	75 mm 11 kg/m³ GW	38	34
			1 x 10 mm Pbd	75 mm 11 kg/m³ GW	47	41
			2 x 10 mm Pbd	75 mm 11 kg/m³ GW	49	44
			1 x 13 mm Pbd	75 mm 11 kg/m³ GW	46	42
			2 x 13 mm Pbd	75 mm 11 kg/m³ GW	48	45
			1 x 16 mm Fyrcheck Pbd	75 mm 11 kg/m³ GW	46	42
	190 mm	400/450 mm Centres	Nil	Nil	36	33
			Nil	75 mm 11 kg/m³ GW	40	35
			1 x 10 mm Pbd	75 mm 11 kg/m³ GW	46	42
			2 x 10 mm Pbd	75 mm 11 kg/m³ GW	47	44
			1 x 13 mm Pbd	75 mm 11 kg/m³ GW	45	42
			2 x 13 mm Pbd	75 mm 11 kg/m³ GW	46	44
			1 x 16 mm Fyrcheck Pbd	75 mm 11 kg/m³ GW	44	41
		600 mm Centres	Nil	Nil	36	33
			Nil	75 mm 11 kg/m³ GW	40	35
			1 x 10 mm Pbd	75 mm 11 kg/m³ GW	47	43
			2 x 10 mm Pbd	75 mm 11 kg/m³ GW	49	45
			1 x 13 mm Pbd	75 mm 11 kg/m³ GW	47	43
			2 x 13 mm Pbd	75 mm 11 kg/m³ GW	48	45
			1 x 16 mm Fyrcheck Pbd	75 mm 11 kg/m³ GW	46	43
	290 mm	400/450 mm Centres	Nil	Nil	41	35
			Nil	75 mm 11 kg/m³ GW	36	33
			1 x 10 mm Pbd	75 mm 11 kg/m³ GW	46	42
			2 x 10 mm Pbd	75 mm 11 kg/m³ GW	47	44
			1 x 13 mm Pbd	75 mm 11 kg/m³ GW	45	42
			2 x 13 mm Pbd	75 mm 11 kg/m³ GW	46	44
			1 x 16 mm Fyrcheck Pbd	75 mm 11 kg/m³ GW	44	41
		600 mm Centres	Nil	Nil	41	35
			Nil	75 mm 11 kg/m³ GW	36	33
			1 x 10 mm Pbd	75 mm 11 kg/m³ GW	47	44
			2 x 10 mm Pbd	75 mm 11 kg/m³ GW	49	46
			1 x 13 mm Pbd	75 mm 11 kg/m³ GW	47	44
			2 x 13 mm Pbd	75 mm 11 kg/m³ GW	48	45
			1 x 16 mm Fyrcheck Pbd	75 mm 11 kg/m³ GW	46	43

Table 19: R_w and R_w+C_{tr} Ratings, 19 mm T&G Hardwood flooring or particleboard to top of joists

Notes:

1 With the substitution of 12 mm overlay flooring for 19mm, the performance is reduced by -1 R_w point.

(iii) Tiles on 6mm Tile underlay over 15mm plywood or 19mm particleboard to top of joists

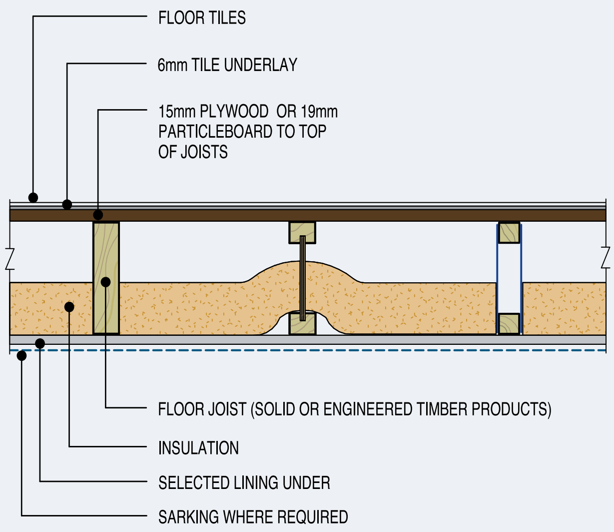


Figure 29: Tiles on 6mm Tile underlay over 15mm plywood or 19mm particleboard to top of joists

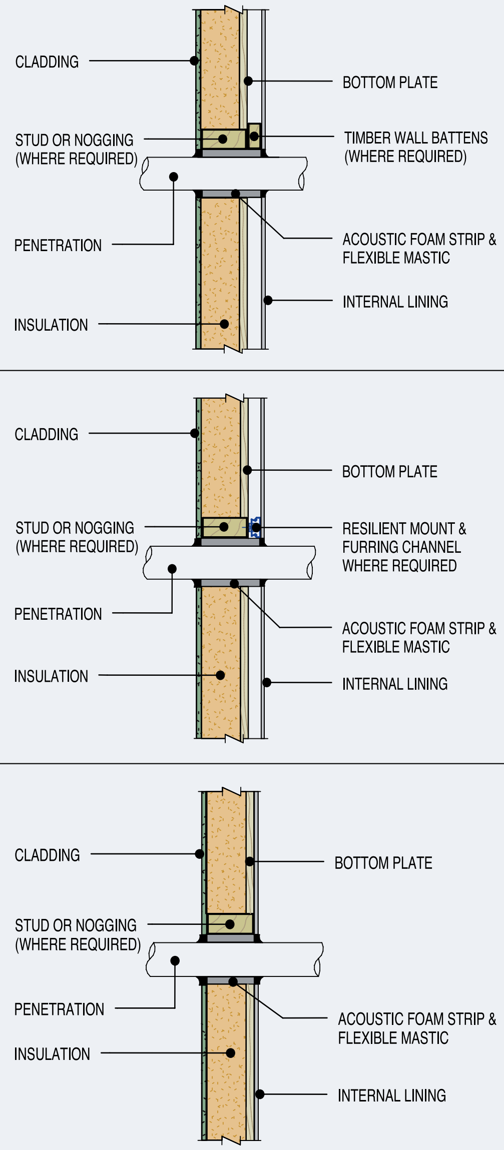
Floor Material	Joist depth (mm)	Joist Layout	Lining to Underside	Insulation	R_w	$R_w + C_{tr}$
Tiles on 6 mm Tile underlay over 15mm or 19mm particleboard	90 mm	400/450 mm Centres	Nil	Nil	38	35
			Nil	75 mm 11 kg/m^3 GW	41	36
			1 x 10 mm Pbd	75 mm 11 kg/m^3 GW	48	43
			2 x 10 mm Pbd	75 mm 11 kg/m^3 GW	49	45
			1 x 13 mm Pbd	75 mm 11 kg/m^3 GW	47	43
			2 x 13 mm Pbd	75 mm 11 kg/m^3 GW	48	45
			1 x 16 mm Fyrcheck Pbd	75 mm 11 kg/m^3 GW	46	43
		600 mm Centres	Nil	Nil	38	35
			Nil	75 mm 11 kg/m^3 GW	41	36
			1 x 10 mm Pbd	75 mm 11 kg/m^3 GW	49	47
			2 x 10 mm Pbd	75 mm 11 kg/m^3 GW	51	47
			1 x 13 mm Pbd	75 mm 11 kg/m^3 GW	49	44
			2 x 13 mm Pbd	75 mm 11 kg/m^3 GW	50	47
			1 x 16 mm Fyrcheck Pbd	75 mm 11 kg/m^3 GW	48	44
	190 mm	400/450 mm Centres	Nil	Nil	38	35
			Nil	75 mm 11 kg/m^3 GW	42	36
			1 x 10 mm Pbd	75 mm 11 kg/m^3 GW	48	44
			2 x 10 mm Pbd	75 mm 11 kg/m^3 GW	49	46
			1 x 13 mm Pbd	75 mm 11 kg/m^3 GW	47	46
			2 x 13 mm Pbd	75 mm 11 kg/m^3 GW	48	46
			1 x 16 mm Fyrcheck Pbd	75 mm 11 kg/m^3 GW	46	43
		600 mm Centres	Nil	Nil	38	35
			Nil	75mm 11 kg/m3 GW	42	36
			1 x 10 mm Pbd	75mm 11 kg/m3 GW	49	46
			2 x 10 mm Pbd	75mm 11 kg/m3 GW	51	48
			1 x 13 mm Pbd	75mm 11 kg/m3 GW	49	46
			2 x 13 mm Pbd	75mm 11 kg/m3 GW	50	47
			1 x 16 mm Fyrcheck Pbd	75mm 11 kg/m3 GW	48	45
	290 mm	400/450 mm Centres	Nil	Nil	38	35
			Nil	75 mm 11 kg/m^3 GW	42	36
			1 x 10 mm Pbd	75 mm 11 kg/m^3 GW	48	45
			2 x 10 mm Pbd	75 mm 11 kg/m^3 GW	49	46
			1 x 13 mm Pbd	75 mm 11 kg/m^3 GW	47	44
			2 x 13 mm Pbd	75 mm 11 kg/m^3 GW	48	46
			1 x 16 mm Fyrcheck Pbd	75 mm 11 kg/m^3 GW	46	43
		600 mm Centres	Nil	Nil	38	35
			Nil	75 mm 11 kg/m^3 GW	42	36
			1 x 10 mm Pbd	75 mm 11 kg/m^3 GW	49	46
			2 x 10 mm Pbd	75 mm 11 kg/m^3 GW	51	48
			1 x 13 mm Pbd	75 mm 11 kg/m^3 GW	49	46
			2 x 13 mm Pbd	75 mm 11 kg/m^3 GW	50	48
			1 x 16 mm Fyrcheck Pbd	75 mm 11 kg/m^3 GW	48	45

Table 20: R_w and $R_w + C_{tr}$ Ratings, Tiles on 6mm Tile underlay over 15mm plywood or 19mm particleboard to top of joists

Gaps, Services and Penetrations

Design of a wall or roof/ceiling system should consider services and penetrations from other building elements. Penetrations in a system can compromise its acoustic performance and will require extra consideration. For external walls it is also important not to chase services into masonry or concrete walls.

- All penetrations in sound-rated building elements should be neatly cut or drilled. Avoid excessively sized penetrations.
- The wall around any large penetration should be rebuilt with the same material. Small residual gaps at penetrations can be sealed with suitable mastic.
- The normal tolerance in building construction should be considered when installing penetrations, and at wall/floor junctions. Revised detailing is needed where residual gaps are too large to allow effective sealing with mastic.
- Gaps around all penetrations in sound-rated walls or ceilings should be treated and sealed to maintain acoustic ratings.
- Sealing should be effective, resilient, resistant to the surrounding environment, and designed to last for the life of the building.



Figures 30, 31, 32: Examples of penetration through wall of building elements

5

Further Information

5.1 Opinions and Assessment Report

The acoustic advice, assessments and opinions contained in this Guide have been based on a report, prepared by acoustic engineers, ASK Consulting Engineers Pty Ltd, South Brisbane. QLD. 4101, February 2012.

Qualified consultants can be found through the professional body, the Association of Australian Acoustical Consultants (AAAC) www.aaac.org.au

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Impact and Assessment of Moisture-affected Timber-framed Construction

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Table of Contents

Introduction

Timber-framed construction is robust and resilient when subjected to adverse and extreme conditions, including those associated with moisture.

During construction, issues may arise that bring building to a halt, leaving frames and other parts of a building exposed to the weather for a time. Bad weather can also lead to properties being flooded. In rarer situations, flooding is caused by storm tidal surges in coastal areas.

When timber-framed construction experiences the effects of moisture, there are no simple rules to assess the impact. Each individual case will need to be assessed to determine the extent of any degradation, and the rectification or repair required. Factors and variables that can influence the effect of moisture exposure and rectification include:

- macro and micro climatic conditions
- length of time of exposure
- number and intensity of rain days
- sun exposure
- drying conditions and prevailing winds
- temperature
- degree of protection from weather
- for flood or tidal surge, length of time of inundation
- if the water is contaminated with chemicals or sewage, etc.

When unfinished houses and house frames have been exposed to the weather, the level of degradation depends on a combination of these factors. Some structures will require extensive repair after a few months' exposure; others may be quite serviceable after 12 months' exposure.

Similarly, for flood-affected properties, short periods of inundation, typically 1-2 days, will not necessarily lead to any permanent, long-term damage to solid timber or engineered timber products, provided they are cleaned and allowed to dry out quickly.

When assessing moisture-affected buildings, consider the detail and extent of investigations. In many instances, the benefit of undertaking simple on-site assessments, with subsequent repair or replacement where necessary, may outweigh the costs associated with more detailed scientific site or laboratory testing and analysis, which may involve chemical analysis or strength testing, etc.

Scope

This Guide has been prepared to assist the building industry and owners understand the key issues and factors that need to be considered when assessing moisture-affected timber construction and to provide some guidance on how to address these considerations. The information contained in this Guide should not be considered in isolation; where appropriate, relevant expertise should be obtained to supplement any information in this guide. The Guide does not cover matters associated with the overall structural stability or adequacy of a building.

Regulatory Requirements

This publication focuses on the assessment of moisture-affected timber construction. It does not address structural adequacy of buildings or other requirements under the Building Code of Australia (BCA). From time to time the BCA is amended and individual States/Territories may also vary requirements. Users of this Guide should make themselves aware of any changes or differences and should develop a full understanding of the resulting implications. This Guide should be used only on this basis.

1 Timber-framed Construction Exposed to the Weather

Timber-framed buildings may be left exposed to the elements for many reasons, from relatively short-term normal weather exposure during construction to prolonged exposure, as sometimes happens when building contracts falter. When investigating the impact of the exposure, each case will need to be individually assessed to find the extent of any degradation and whether this needs to be repaired or rectified. In most cases, even frames that have been exposed for well in excess of three months can be easily and satisfactorily repaired where necessary. Many of the situations highlighted in this section represent extreme examples.

1.1 Inspection Considerations

When inspecting weather-exposed timber construction, the main issues to consider are:

Each case of exposure needs to be individually assessed to find the extent of any degradation and whether this need to be repaired or rectified.

Weathering/mechanical degradation of timber/components: The changing moisture content of timber and timber products exposed to cycles of rain and sun can swell and shrink the timber. The degree to which this occurs will depend on many factors, including the timber's inherent properties, such as shrinkage and density, as well as any protection, such as paint.

Shrinkage and swelling can result in the timber checking, cracking and splitting, as well as connections being loosened. Sheet products may also warp or bow between their supporting members. Where truss plates embedded in timber are exposed to the weather, they too can work loose and, in some extreme cases, may become totally dislodged.

Moisture content: Timber and timber products are hygroscopic so they will take up or lose moisture in harmony with their surroundings. The moisture content (MC) of solid timber and timber products such as laminated beams can be easily measured on-site using moisture meters (see Appendix 1). The use of meters to measure the moisture content of some treated timber products – as well as plywood, LVL and other wood-based boards including particleboard and OSB – is not reliable. In these cases, where a moisture content is required, consider oven dry testing (see Appendix 1).

Moisture content measurements are a useful indicator for a number of issues, such as potential for moulds, stains and decay as well as suitability of frames to be enclosed with linings or to have surface finishes applied.

Mould and fungal degradation (decay): Where the timber's moisture content exceeds about 20% for prolonged periods, there can be fungal degradation or decay, particularly in untreated timber of low natural durability. Fungal degradation should not, however, be confused with moulds or stains, which may look unsightly but may only just be on the surface of the timber, with the underlying wood unaffected.

Timber frames exposed to the weather for six months.

Exposed timber can become discolored and stained.

Potential for insect damage: Building assessments should consider the potential for insect attack, particularly termites, due to degradation of insect management systems used in the original construction. Termite management systems include the use of treated termite-resistant timber, chemical barriers applied to the soil and physical barriers. Some termite-treated timber products may only have warranties that are valid for normal periods of weather exposure and some ground line chemical barriers may be compromised where exposed to continuous moisture. Reinstatement of the original termite management system or provision of an alternative system may be required in some instances of prolonged exposure.

Corrosion: Corrosion of metal fasteners, from nails to heavier connections such as bolts or plates, can be accelerated where moisture is present, particularly where the connections are used in or on some timber treatment types such as CCA, ACQ and copper azole. Where necessary, some embedded fasteners may also need to be extracted to assess level and extent of corrosion. Corrosion of fasteners in construction close to marine environments may also need thorough inspection.

1.2 Specific Issues

1.2.1 Moisture Content Measurements in Framing

Moisture content 20% or above is conducive to decay and needs to be addressed.

The moisture content of framing should be measured using an electrical resistance moisture meter with a hammer probe that has insulated prongs. The readings will give a good indication of the current state of timber and an idea of future conditions that may arise or actions that may be needed to lower the moisture content to a level suitable for finishing off and lining frames, etc. A meter with a hammer probe and insulated prongs allows measurements at depth (say 10 to 15 mm) which will be a better gauge of actual moisture in the timber than just surface measurement.

Where the moisture content is less than 20%, and remains so, decay will not occur (or continue if it has started) although surface mould and stain may be present. An moisture content 20% or above is conducive to decay and needs to be addressed.

The areas of a weather-exposed frame likely to have the highest moisture content are bottom plates on slabs or sheet floors and the lower ends of studs on these plates due to wicking action.

When taking moisture content readings, chose a random selection of bottom plate and stud positions and record measurements for the plate, lower end of the stud and 500-600 mm up the stud. Take random measurements in other solid members such as beams, top plates, and truss or roof framing.

Water ponding on slab. Note wicking of moisture up the studs.

Where moisture contents are less than 16%, framing is considered suitable for installation of lining products such as plasterboard.

Table 1.1 gives a typical example of moisture contents taken from a site on a weather-exposed frame at bottom plates to slab.

The measurements in Table 1.1 indicate:

- High MCs in bottom plates and lower end of studs conducive for decay to occur. These need to be allowed to dry as quickly as possible.
- Lower MCs up the studs away from plates/slab, but some additional drying required.

Table 1.1: Typical moisture content readings

Position (various locations on site)	Deltron Resistance Meter Readings at 10 – 15 mm depth (%)		
	Bottom	Bottom stud	Stud at 500 mm up
1	16	16	14
2	23	21	17
3	>25	>25	18
4	19	21	17
5	23	22	18

Notes:
1. All studs and plates H2 Treated. H2 only protects against termites, not decay.
2. Plates MGP 10 pine and studs MGP 10 and MGP 12 pine.

1.2.2 Moulds, Stains and Decay

Unprotected timber exposed to the weather can show considerable discolouration (white chalky look, through to very dark blue stains) due to moulds and stains. These moulds and stains 'live' on the sugars and starches naturally present in the timber, particularly in sapwood. In all but extreme circumstances, they do not affect the mechanical or strength properties of the timber.

Their impact can be easily established by scraping back the timber surface. Where the timber just below the surface is similar to 'fresh' timber, there will have been negligible or no deterioration.

Decay fungi, on the other hand, have the ability to degrade timber and wood-based products by attacking the cellular structure. Decay affecting the timber's strength properties can be easily assessed on-site by 'picking', probing or drilling using a fine auger or drill bit.

With the 'picking' technique, decay near the surface of the timber is found by trying to prize a splinter from the wood using a pocket knife, small screwdriver or similar implement. If the timber is still sound, relatively long splinters should be able to be lifted out. If the timber has commenced to decay, the wood will break abruptly in a brash or carroty nature.

The probing technique compares the 'hardness' of sound, non-affected wood to that which is believed to be affected. Timber affected by decay will feel softer and more 'spongy' than sound timber.

Drilling using a fine auger or drill bit enables assessment deeper into the timber. Again, for the equipment being used, the force required to penetrate sound timber should be compared to the force required to penetrate affected timber. Timber that has decayed will be far more easily penetrated.

Reasonably reliable assessment using these techniques will take experience.

Assessment of timber decay takes experience; the force to penetrate both sound and affected timber should be comparable.

Significant discolouration due to stain but timber under surface is unaffected, with no decay.

Decay in bottom plate on particleboard floor. Note small drill holes on top of plate used to detect decay.

1.2.3 Sheet Bracing

Common forms of wood-based sheet bracing products include both structural plywood and orientated stand board (OSB).

With all sheet bracing types, the critical areas for evaluation are the sheet edges where the nail or other fasteners attach the sheet to the frame. Any degradation of the sheet edges will compromise the structural adequacy and shear capacity of the fasteners which, in turn, will affect the design capacity of the bracing.

The following photographs illustrate situations where the adequacy of sheet bracing has been compromised due to degradation of the sheets.

When assessing sheet bracing panels, one suggested method is to use a qualitative rating system such as:

- Rating 1 = Considered sound as exists, no need for rectification.
- Rating 2 = Minor concerns re delamination/appearance/bowing between studs.
- Rating 3 = Action required to bring up to standard.
- Rating 4 = Replace or repair as considered structurally inadequate.

Sheet edges are critical areas for evaluation.

Example of OSB sheet bracing showing edge swelling and flaking.

Plywood delamination at bottom plate in bracing panel. Note: The plywood used in the construction in the above example had no identification stamps or indication of certification schemes or Australian Standard for its manufacture.

Table 1.2 is a site assessment of plywood bracing undertaken on a house frame weather exposed for more than six months.

Table 1.2: Typical example of a sheet bracing rating assessment.

Bracing panel number	Rating	Comments
1	1	–
2	3 – 4	Double-sided (plywood bracing both sides of wall)
3	3 – 4	Double-sided
4	4	Double-sided – extensive delamination one side at bottom plate – other side not as severe
5	3	Bad delamination in corner plus spot delamination
6	4	Severe at critical points

Notes:
1. The panel numbers and rating were the results of this assessment at various locations.
2. The high moisture contents and prolonged exposure have also caused some buckling (and 'odd' nail popping) of the ply bracing, which at this stage is not considered serious. Fitting additional rows of nogging between studs and additional nailing will eliminate this.

1.2.4 Particleboard Flooring

Particleboard flooring exposed to prolonged weather is generally more sensitive to moisture uptake along sheet edges. Where possible, it is important to obtain the manufacturer's details (usually on the underside of the flooring) and identify the product type and other details, including original board thickness.

Assessing the particleboard on-site will be similar to all wood-based composites made from chips, flakes, strands or fibres: establish flaking or loose fibres and any swelling that has occurred.

Edge swelling can be assessed by using a straight edge across the sheet (approximate only as the measurement may be a combination of swelling or board deflection, etc). However, it is preferable to take a hole saw sample: measure the thickness of the sample and compare it to the manufacturer's stated thickness (usually 19 mm for 450 mm joist spacing or 22 mm for 600 mm spacing in residential housing). Hole saw samples can also be obtained from the body of the sheet where necessary.

An additional advantage of taking hole saw samples is that the moisture content in the board can be ascertained by oven dry testing. This also enables the thickness of the sample to be measured following drying to determine the extent of any non-recoverable swelling.

Taking a hole saw sample of particleboard flooring means you can compare the sample to the manufacturers stated thickness.

Typical hole saw samples.

Measuring the thickness of particleboard flooring at a hole saw sample location.

As a general guide, where the non-recoverable (after the flooring has been allowed to dry out) edge swelling in particleboard flooring exceeds about 2-3 mm within 50 mm of sheet edges (supports), the long-term structural adequacy of the floor is likely to have been compromised. It will need to be replaced or subjected to alternative rectification such as an additional overlay structural floor.

If there's doubt about the damage, 600 x 450 mm samples of flooring that has been allowed to dry can be cut from the floor and forwarded to a testing laboratory to ascertain if the flooring still has the required structural properties.

1.2.5 Plywood Flooring

Structural plywood flooring is less susceptible to moisture effects and edge swelling than particleboard. Provided there has been no delamination of veneers (unlikely in quality-certified structural plywood), the plywood will usually maintain its structural adequacy, even with prolonged weather exposure. Once dry, light sanding should remove any minor residual edge swelling.

NOTE: Particleboard and plywood floors that are retrievable may in some cases benefit from adding additional fasteners (screws, screw shank nails, etc). If additional fasteners are installed, minimise splitting of joists by using small diameter fasteners or by pre-drilling.

Where there is any concern regarding structural adequacy, the product manufacturer or a structural engineer should be consulted to advise on repair or replacement.

1.2.6 Tongue and Groove Flooring

It is unlikely that a feature tongue-and-groove (T&G) floor will have been installed in a house where the floor could still be exposed to the weather. If, however, this has occurred, the flooring can be assessed as described in Section 2.

1.2.7 Floor Joists (solid timber and engineered timber products)

Moisture can track down fittings into joists, creating local decay pockets.

The tops of solid, glued-laminated or LVL joists or top chords of engineered joists, particularly low-durability timbers, should be assessed for decay by initially drilling adjacent to floor fixings. Moisture can track down the fixings into the joists, creating local decay pockets around the fixing. Where this occurs, it will compromise both the floor fixing integrity as well as the structural adequacy of the joist. More general drilling for decay may also be warranted if this is found to have occurred.

For nailplate fabricated joists and nail-plated floor trusses, see Section 1.2.10.

In addition to assessing 'I'-joists for decay, it may also be necessary to assess the integrity of the webs and the glued joint at the web to top and bottom chord intersections. Plywood and OSB webs can be assessed visually and also by using the hole saw technique described above.

Decay pockets (highlighted) around fixing points where sheet flooring has been removed after 12 months' weather exposure.

1.2.8 Glue-laminated and LVL Beams

A visual inspection of laminated or LVL beams will generally reveal any checking, splitting or delamination that has occurred due to the weather exposure. Where found, the extent (length and depth) of any splits or delamination should be further assessed and recorded using a ruler/tape and fine feeler gauge to establish depth.

Split (indicated by arrow) totally through one of the doubled glued-laminated beams. Depth of split indicated by ruler 35 mm plus.

Split (indicated by arrow) along second top laminate (does not follow glue line) at end of beam.

1.2.9 Finger-Jointed Products

Finger-jointed timber product performance depends on the type of glue (waterproof, water-resistant or other) used in its manufacture. Little degradation from weather exposure is expected with the phenolic or resorcinol types, compared to possible significant degradation with some melamine urea formaldehyde or cross-linked PVA types. The integrity of prolonged weather exposed finger-jointed framing should be assessed via random sampling from the site followed by mechanical testing.

1.2.10 Nail-plated Members (roof and floor trusses, etc)

Repeated cycles of wetting and drying of nail-plated (truss plates) timber products frequently leads to the nailplates 'withdrawing' from the timber due to the associated cyclic expansion and contraction in the timber. In extreme cases, the plates may totally disengage. Where the gap between the plates and the timber is more than 1-2 mm, which can be measured using feeler gauges, the structural integrity of the members or product may be severely compromised. If the structural integrity is in doubt, the nail plate/product manufacturer's advice on repair or replacement should be sought.

Repeated cycles of wetting and drying of nailed plated timber often leads to the nailplates loosening.

Loose truss plates where trusses exposed to weather for six months (prior to roofing being installed).

1.2.11 Loose Straps and Tie-down Connections

As shown in the example below, the weather exposure of frames can cause connections such as straps and tie-down rods to become loose. This can be due to either minor frame settlement and/or wetting and expansion of the timbers and subsequent drying and shrinkage. These situations will not usually be due to degradation of the timber in the frames and can be easily rectified. They should not present any real structural concerns.

Loose tie-down steps due to timber expansion and then subsequent shrinkage.

1.2.12 Termite Management

Termite management systems warranties should be checked to ascertain their positions on weather exposure.

Termite management can include physical or chemical systems. Chemical barriers can be compromised over time if fully exposed to the weather. Similarly, if timber frames are treated for termite protection using a H2/H2F/H2S treatment (refer to AS 1604), prolonged weather exposure can have a detrimental effect and may void any manufacturer warranty on the treatment.

For perimeter chemical barriers, a licensed pest control company should be engaged to reinstate perimeter treatments and to check any other management systems originally applied.

For termite-treated timber or wood-based products, samples of the timber can be sent to a testing laboratory to determine if the timber complies with AS 1604. Alternatively, a licensed pest controller can be engaged to install a different type of compliant termite management system.

1.2.13 Treatment of Mould

Mould and blue-stain can occur on weather-exposed timber. While unsightly, much of it will not be detrimental to the timber's long-term integrity, provided it is allowed to dry quickly. Moulds and stains may pose future concerns if not addressed with respect to health issues and the finishing of internal linings. When the surface is dry, a pH-neutral, boron-based mouldicide should be applied to the frames.

Commercial contractors are available to undertake this task and boron-based mouldicides have an added termite protection capability. However, it may not be recognised as an official termite treatment under Australian Standards when applied on-site.

2

Flood-damaged Timber and Timber-framed Construction

Before flood damage is assessed or repaired, a licensed electrician must undertake an electrical safety inspection. An appropriately licensed person should also carry out a plumbing safety inspection. In addition, an inspection and assessment of structural damage to buildings and houses should be undertaken by a competent person, such as a registered structural engineer, building certifier or licensed builder. Where there has been structural damage, repairs should be undertaken in accordance with, and under the direction of, professional advice.

2.1 Assessment of Damage

Important timber and timber-related issues to consider when assessing structural damage include:

- Scoured out footings/foundations and supports (check that dried out mud/silt not hiding damage)
- Damaged tie-down connections
- Cracked or broken members
- Damaged sheet bracing (lining materials)
- Loose joints and connections
- Damaged trusses and truss plates
- Adequate seating and bearing of members
- Truss plates not firmly seated in timber
- Gaps between support points and joints
- Girder trusses (trusses that support other trusses)
- Corrosion of fasteners/connections
- Corrosion of steel posts in concrete footings

NOTE: Where fast-flowing water has hit the dwelling, joists and bearers may have shifted/twisted and walls and windows may be out of square, etc. Any excessive misalignment should be corrected before new cladding or lining is installed.

Failure to address or correct these types of faults could severely affect the future structural performance of the building.

Footings scoured out by floodwaters (Image: BSA Queensland).

2.2 Timber and Moisture

This information on timber and moisture is in addition to the information provided in Section 1, which should also be considered in flood-affected construction.

2.2.1 Mould and Decay

Timber and wood-based products that have been totally immersed in water for prolonged periods will not decay or be subject to fungal deterioration due to the lack of available oxygen. When the water has receded, it is important to clean the timber of all silt and mud, etc, as soon as possible and then allow the timber and wood-based products to thoroughly dry out as quickly as possible with good ventilation. If power is available, fans, air-conditioners or dehumidifiers can assist with this process.

The space under suspended floors must also be immediately drained and dried out. Make sure all ventilation points are clear of debris and dirt and, if necessary, use forced mechanical ventilation (blowers) to assist in the process.

If timber or wood-based products remain damp or wet for prolonged periods and air (oxygen) is available, mould (dark staining) and eventually decay can occur, particularly in timber that has low natural durability such as untreated pine. Significant degradation or decay of timber is usually preceded by surface discoloration by moulds or stains, but if these are easily scraped off with a knife and the timber is sound underneath, it is not of concern. Degradation or decay in timber will be indicated if the wood has become soft and spongy or is easily penetrated with a knife or screwdriver.

Avoid using chemical products to prevent/treat mould as it can corrode metal connectors and fasteners.

Avoid using products such as chlorine (pool chemicals), etc, to prevent or treat mould due to possible corrosion of metal connectors and fasteners.

Although quite stained and covered with mud and silt, when cleaned, the pine framing found to be unaffected

Locate decay by probing.

Decayed timber is soft and spongy and can easily be penetrated with a knife or screwdriver (see arrow).

Different types and species of timber will vary in the time they take to dry.

2.2.2 Swelling and Shrinkage

Timber and wood-based products that have been saturated will swell. When they dry out, they will shrink. The amount of swelling or shrinkage depends on the type and species of timber or type of wood product, and the time exposed to water. Where timber has swollen in, for example, flooring, it may also have secondary effects such as cupping and pushing out external walls or movement of joists and bearers.

The time it takes for fully saturated timber to dry to an acceptable level will vary considerably, depending on its thickness, density and the level of ventilation. Higher-density timbers, such as hardwood, will take longer to dry. 'Forced' ventilation as noted above can speed up the drying process.

Expansion in flood-affected timber flooring.

Expansion of the hardwood T&G floor above has caused the separation of double bearers (see arrows).

2.3 Kitchen Cupboards, Vanity Units and Laundry Units, etc

Where possible, undamaged parts of bench tops such as granite or stone, sinks, basins and tap ware should be retained for re-use.

If of relatively recent construction, these units are likely to have been made from a composite, wood-based board such as particleboard (chipboard) or medium density fibre board (MDF or 'Craftwood') with either an overlay (e.g. veneer, laminate, vinyl) or surface paint finish.

If these units have been inundated, and have swollen, they need to be replaced. The swelling in the wood-based composite is not recoverable. Also, the surface finishes and their attachment to the underlying board may have been damaged.

If water levels have only covered the kickboards and not wet the carcass of the cupboards, kickboards can be removed and the area under the cupboards cleaned and dried and new kickboards installed.

Moisture, silt and mud, etc, will also be trapped behind these units, so they may need to be removed to gain access for cleaning and drying out of the underlying cavities and frames.

2.4 Roofs, Walls and Floors

Where timber frames have been inundated, it is important that they are cleaned (washed down) and allowed to dry out as quickly as possible. For frames enclosed in cavities (behind wall or ceiling lining), the lining will need to be stripped and removed to allow access for cleaning, removal of insulation and to allow adequate ventilation for drying out.

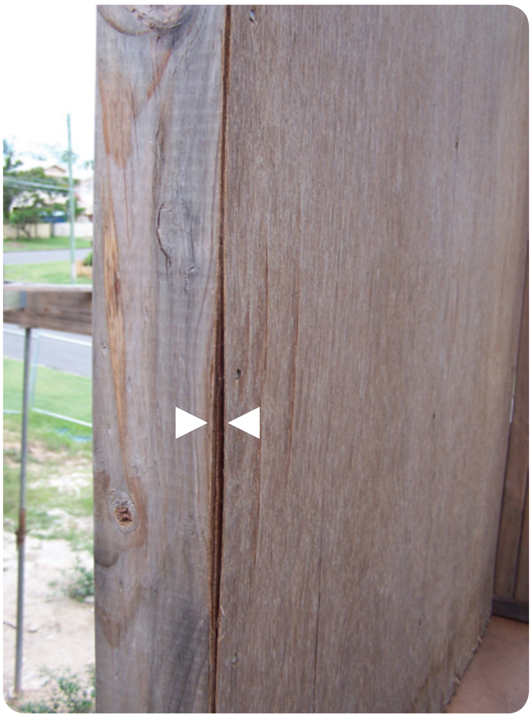
Irrespective of the need to access frames for cleaning, most lining products that have been inundated (T&G, V-Joint, plasterboard, plywood, hardboard ['Masonite'], medium-density fibreboard, etc) will need to be replaced.

Lining should be removed to at least 300 mm above the highest level of inundation (or further if required for adequate re-instatement of the lining, i.e. half or full wall height). Inundated bulk (batts) wall or ceiling insulation will need to be removed and replaced during cleaning and repairs.

Houses built after the mid-1970s may have wall bracing using wall lining materials (plasterboard, plywood, hardboard and fibre cement, etc) as the bracing members. Where wall linings are stripped, temporary diagonal timber braces (70x35 pine) at 30° to 60° should be nailed to the top plate, bottom plate and studs to each wall to maintain the house's bracing strength prior to reinstatement of permanent bracing and wall lining.

WARNING: some roof and wall sheeting and some vinyl flooring coverings in older houses may obtain asbestos.

NOTE: In older houses in particular, some roof and wall sheeting and some vinyl floor coverings may contain asbestos. Do not sand or cut these products. Removal and disposal of these products must be undertaken by appropriately licensed contractors.



Delamination of plywood sheet bracing (see arrows).

Plywood sheet bracing affected by moisture. Replacement required. Where necessary fix temporary braces.

2.5 Laminated Beams, Laminated Veneer Lumber (LVL), 'I'-Beams and Structural Plywood

These products are manufactured using waterproof glues so short-term inundation should not adversely affect their structural adequacy. An inspection can establish if there has been any delamination in the glue lines. If significant delamination has occurred, their structural integrity may have been compromised and replacement or repair will be necessary.

As these products dry out, it is possible that seasoning checks will develop. However, unless they are deep and continuous such as adjacent to glue lines in laminated beams, these checks should not affect structural integrity.

Structural plywood such as flooring and bracing (and exterior plywood cladding) that are manufactured using 'waterproof' (phenolic) glues, should not be structurally affected, but if there is 'bubbling' or delamination of veneers they will need to be replaced.

2.6 Timber Floors and Decks

NOTE: Before any timber floors are re-laid, the services of a professional floor installer should be used to measure and check the moisture content of any underlying substrates (plywood, particleboard or concrete) to ensure that it is suitable for the new flooring to be laid.

2.6.1 Solid T&G Strip Floors Direct to Joists on Bearers

The flooring may continue to swell or expand across the boards for a time, even after the water has subsided, as moisture moves deeper into the timber. After cleaning, assess the extent of swelling and or tenting of boards (lifting off the substrate/supports). Check to see if there is still clearance between the edges of boards and the bottom plates of walls (usually under the skirting board) and to see if the flooring has expanded and started to push wall frames out at the bottom.

If necessary, relieve the pressure on walls by removing or cutting out perimeter boards. Eliminate any trip hazards that may have arisen due to tenting of boards or lifting of nails, etc.

Allow the flooring a minimum of four months to dry out before re-assessing. Gaps between boards are highly likely as the floor dries out, however, the structural adequacy of the flooring is not likely to have been compromised and floors may be lived on in the meantime.

Following re-assessment, consideration can then be given to rectification in accordance with industry recommendations, which may include the following options:

- re-sanding and polishing
- overlaying with a new thinner overlay timber floor
- replacing the floor
- installation of alternative floor coverings.

Tenting of T&G floor due to prolonged moisture being trapped under the floor. This inundated T&G floor supported on a particleboard sub-floor 'tented' about one week after the flood water receded.

2.6.2 Plywood Floors on Joists and Bearers

Plywood, because it is cross laminated, is relatively stable (resistant to expansion) with respect to moisture uptake. Flooring plywood is also manufactured using waterproof glues so delamination of the veneers due to moisture is unlikely.

All flooring should be left a minimum of four months to dry out.

After cleaning, assess the extent of swelling and/or lifting of sheets off the joists. Check to see if there is still clearance between the edges of sheets and the bottom plates of walls (usually under the skirting board). If necessary, relieve the pressure on bottom wall plates by provision of relief cuts in the sheet edges as close to bottom plates as possible. Eliminate any trip hazards that may have arisen due to lifting sheets or nails and screws, etc.

Allow the plywood flooring a minimum of four months to dry out before reassessing and carrying out any rectification that may be required. The structural adequacy of the plywood flooring is not likely to have been compromised.

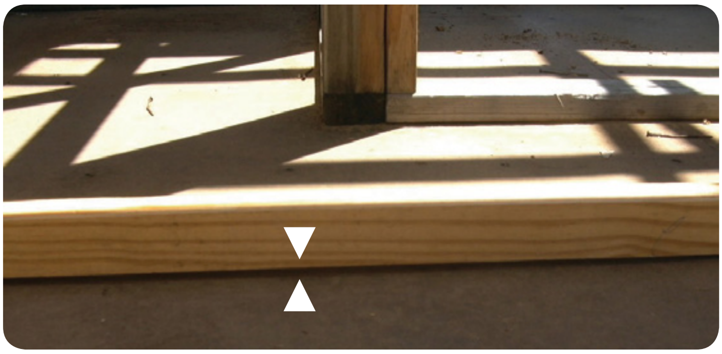
2.6.3 Particleboard ('Chipboard') Floors on Joists

Particleboard flooring is more susceptible to moisture-induced swelling than timber or plywood, particularly at sheet edges. Depending on the type of particleboard (some boards are manufactured using moisture-resistant glues), it may have suffered a loss of structural integrity. There will be only minor loss of swelling when the particleboard dries out.

After cleaning, assess the extent of swelling and/or lifting of sheets off the joists. Check to see if there is still clearance between the edges of sheets and the bottom plates of walls (usually under the skirting board). If necessary, relieve the pressure on bottom wall plates by provision of relief cuts in the sheet edges as close to bottom plates as possible. Eliminate any trip hazards that may have arisen due to edge swelling, lifting sheets or nails and screws, etc.

Allow the particleboard flooring a minimum of four months to dry out before re-assessing and carrying out any rectification that may be required. As a guide, if sheet edges have swollen more than 5 mm (i.e. would need to be sanded back by 5 mm or more to get a flat floor) then the structural adequacy of the flooring has been compromised and needs rectification by either replacement or installation of a new structural floor over the existing particleboard. Where there is doubt as to the structural adequacy of the particleboard floor, consult the flooring manufacturer.

Floors that are retrievable may benefit from the fitting of extra rows of noggings glued/fastened between the top of noggings and the under-side of the floor to help stiffen and eliminate squeaks.



Use a straight edge to estimate edge swelling in particleboard flooring.
Gap between straight edge and floor (see arrows) indicates edge swelling in particleboard flooring.

2.6.4 Timber Floors on Concrete Slabs (includes overlay, T&G on ply or battens, direct fix, etc)

With floors of this type, moisture, mud and silt will have become trapped under the floor surface. This will result in significant expansion in the flooring as it takes up moisture resulting in peaking and tenting. This will necessitate these floors to be removed and replaced as it is highly unlikely that an acceptable floor will be able to be obtained from the original floor.

Once the flooring system has been removed and the slab cleaned, leave the slab for a minimum of 3-4 months to allow for dry out (a rule of thumb is one month per 25 mm of slab thickness – consider the impact of edge and internal stiffening beams). The moisture content in the slab should then be checked by a professional floor installer to ascertain if it is sufficiently dry to enable a new timber floor system to be installed. Moisture vapour barriers over the slab should also be considered prior to laying the new floor.

2.6.5 T&G, Overlay or Floating Floors on Plywood or Particleboard on Joists

These dual-layer floors will take considerably longer to dry out than single-layer floors. In addition to the considerations noted above for solid T&G, plywood, particleboard and also floors over slabs, the upper flooring surface of these floors will probably dry unevenly with a moisture gradient (low moisture content on top surface to high on underside of the flooring/sheet floor interface) that will result in significant cupping of the top boards.

It is unlikely that the upper floor surface of these flooring systems will be able to be reinstated to a level of finish considered acceptable for a feature floor. It may, therefore, be prudent to remove the upper layer as soon as possible to enable the structural plywood or particleboard substrate to dry out and be assessed for suitability of laying a new flooring surface over the top when appropriate.

It must also be considered that removal of the timber floor, where adhesives are usually used, may result in significant damage to the plywood or particleboard subfloors and their fixing to joists. In some instances, the plywood or particleboard will need to be replaced.

Irrespective of whether the plywood or particleboard remains or is replaced, screw fixing to the joists is needed. Particular attention should be paid to ensure sufficient fixing is provided across the width of the sheets.

2.6.6 Wet Area (bathrooms, laundries, etc) Floors Laid Over T&G, Plywood or Particleboard Subfloors on Joists

Under current and recent building regulations, these floors are required to have a waterproofing system above the T&G, particleboard or plywood. Typical waterproofing systems include seamless vinyl flooring and, under tiled floors, waterproof coating systems such as fibreglass applied directly to the timber flooring substrate. These waterproofing systems significantly inhibit the ability of the timber substrate flooring to dry out quickly. These floors may require special attention to drying and/or repair/ replacement.

2.6.7 Timber Decks

Due to their normal weather exposure conditions, timber decks are required to be constructed of durable timber and should only require a thorough clean and then be allowed to dry. If any decking has lifted or become loose, after it has dried out it can be carefully re-nailed or screwed. Then use a proprietary decking cleaner and follow with a compatible decking finish. If re-sanding the decking is contemplated, consider whether this will compromise the deck fixings used, i.e. galvanised coatings on nails, etc.

2.7 Timber Stairs

Solid timber stairs can usually be recovered after inundation if surface material are removed quickly.

Stair systems constructed using medium-density fibreboard or non-flooring grade particleboard can be significantly affected by inundation and will not normally be recoverable requiring replacement.

Stairs constructed from solid timber (hardwood or softwood), glued-laminated timber or structural plywood can usually be recovered provided any surface materials, such as carpet, attached to the underlying stair structure are removed, and the stairs are allowed to dry quickly. Because of their nature, with many housed joints, etc, forced mechanical ventilation or dehumification may be required to enable timely drying of the stair system.

After the stair structure has been allowed to dry, liberal application of a PVA or similar wood adhesive glue between risers, treads, end of treads, etc, and nailing with small diameter c-brads to help minimise splitting, will further stiffen and help reduce squeaks. Further gluing /nailing of existing cleats can also be considered.

Solid timber stairs stripped out and allowed to dry were recovered following inundation.

2.8 Termite/pest management

Flooding and inundation may have compromised the termite management systems used to protect homes and buildings. In homes or extensions and renovations carried out since 1990, a notice should have been fixed inside the meter box (or the cupboard under the kitchen sink) that describes the termite management system that has been used.

Floods can also trigger outbreaks of other insects such as cockroaches, silverfish, fleas, etc. While they are not detrimental to timbers, they can be dealt with before claddings and linings are restored by treating cavities. Rat and mice plagues can also be triggered by flood events. If left uncontrolled, they may lead to significant damage to electrical wiring, etc.

2.8.1 Elevated, lightweight timber homes with suspended floors on stumps

Termite management of these traditional forms of construction (unless built in underneath) is usually by means of ground separation and the use of physical barriers such as ant caps and metal termite shields. These barriers and shields should be inspected to ensure they are not damaged or covered by silt or mud, etc, and that the building and any attachments do not provide concealed access for termites to get into the house.

2.8.2 Single or two-storey houses on slabs or where houses have been built-in underneath on a slab

A licensed pest controller should inspect and assess the termite management system used and reinstate this in accordance with the requirements of the BCA, relevant Australian Standard (AS 3660.1) and manufacturer's recommendations. Systems that are likely to have been compromised due to water, silt and mud build up, etc, include all chemical barriers and physical barriers such as stainless steel mesh ('Termimesh') and graded stone ('Graniteguard').

Licensed pest controllers should inspect, assess and treat inundated properties.

2.8.3 Termite-treated framing

Some homes and buildings may have been constructed using H2 termite treated framing ('T2', 'True Blue' and other similar trade names such as 'Blue' treated timber framing) as a primary or secondary means of termite management. Refer to AS 3660.1 and AS 1604.1. Some of these treatments rely on an envelope of the termiticide preservative that is applied to the timber at the time of manufacture. Short-term water inundation is ***unlikely*** to have compromised this envelope, however, it is still recommended that a licensed pest controller carry out reinstatement of termite management systems using an additional physical or chemical termite barrier system as noted above.

2.9 Corrosion

Pay attention to potential impacts of corroded metal components.

When assessing timber construction, pay attention to the potential impacts of corroded metal components and connections. Pay particular attention to any non-galvanised items, including bright steel nails, bolts or screws and also to galvanised components such as SHS posts or stirrups that are embedded in concrete and will be susceptible to corrosion at the top of footing. It may be necessary to remove some items (screws/bolts, etc) to assess the extent of corrosion on the embedded portion of the fastener. Where rust is present but the posts are still viable, they should be cleaned, treated with phosphoric acid, and then sealed with a metal primer, followed by subsequent coats of a metal or bituminous paint product.

Significant corrosion of embedded galvanised steel post bracket.

3

Additional Considerations for Buildings Affected by Tidal Surges

Recent experience from assessments of properties in North Queensland affected by coastal tidal surges following Cyclone Yasi clearly indicated that houses and other buildings constructed on elevated floor platforms ('highset' style houses that were predominantly open underneath) performed very well. Conversely, adjacent lowset houses on slabs suffered extensive structural damage and in many cases total destruction.

3.1 Structural Effects

Storm and tidal surge can apply significant impact and hydrodynamic forces on houses, particularly on walls that are normal (right angles) to the direction of waves.

A number of optional design strategies can be used to address these actions, from the use of very robust foundation and wall materials to the more practical alternative of raising the floor levels of buildings above the expected height of the storm surge.

While assessment and repair of repairable parts of tidal surge-affected buildings generally follow the same recommendations as for flood-affected properties, the structural considerations need specific attention.

The Queensland Reconstruction Authority (RCA) has published a guide that can assist in this regard. Refer to 'Further Advice and Valuable Information' below for a link to download the free RCA guide.

Storm surge damage to a slab on ground house.
(Image: Cyclone Testing Station, James Cook University, Townsville)

Elevated houses suffered little storm surge damage.
(Image: Cyclone Testing Station, James Cook University, Townsville)

Storm surge structural damage. (Image: Cyclone Testing Station, James Cook University, Townsville)

3.2 Salt and Corrosion

All recoverable metal components and fasteners should - where possible - be washed with fresh water and allowed to dry.

An additional consideration with tidal surge is the potential for salt water to corrode metal components and fasteners. Buildings constructed in tidal surge areas are, by nature, usually close to the coastline so the original metal components and fasteners should be of highly corrosion-resistant materials including hot dipped galvanised and stainless steel, etc.

Irrespective of the original materials, where components and parts are deemed recoverable or repairable, metal components, fasteners and similar should – where possible – be exposed and washed down with fresh water to remove salt deposits and then allowed to dry.

3.3 Design Considerations

There are a range of other building design considerations that should be considered in the siting, orientation and design of buildings in surge-prone areas. Many of these are addressed in the RCA Guide referenced above.

A

Appendix A – Moisture Content

A1 Introduction

The following information on moisture in timber outlines the various methods used to test the moisture content of timber.

A2 Moisture Content

Moisture content (MC) is simply the mass of moisture present in wood divided by the mass of the wood with no moisture in it, expressed as a percentage.

What is important about the MC in timber is that a board's cross-section will increase with increasing MC and will decrease with decreasing MC. At the time of machining, cover width variations are usually minimal and subsequent variations that occur in board widths are usually due to changes in MC. It is often the current and future variations in board dimensions that are of primary importance and the purpose of moisture content testing is to indicate what future movement can be expected.

By simply looking at the dimensions of timber, such as cover width in flooring, it is often possible to obtain information about the timber's MC. For example, many dressed timber products are machined to nominal dimensions in the seasoned condition. Flooring, for example, may be originally dressed to a cover width of 80 mm, so if the width of flooring measured ***in situ*** is say 81.5 mm, this would indicate that the boards have taken up moisture since manufacture. If the dimensions were less than 80 mm it could indicate the boards were at a lower moisture content than at manufacture.

Australian Standards that cover the moisture content of seasoned products vary in their limits as this depends on the species and application. Table A1 provides some information on species, associated products and the moisture content tolerances set out in the applicable standard. The number of the standard is also provided.

Table A1

Species Group	Seasoned Product	Moisture Content Range (anywhere within x-section)	Australian Standard
Hardwood	Flooring. Lining, dressed boards	9 to 14%	AS 2796
	Decking	10 to 18%*	AS 2796
	Framing (seasoned)	– 90% pieces < than 15% – All pieces < 18%	AS 2082
Softwood	Flooring. Lining, dressed boards	9 to 14%	AS 4785
	Decking	10 to 18%*	AS 4785
	Framing (seasoned)	– 90% pieces < than 15% – All pieces < 18%	AS 2858
Cypress	Flooring, decking	10 to 15%	AS 1810

*A maximum moisture content of 15% is recommended.

How moisture content is measured

Moisture content (MC) is generally measured by either a moisture meter or through oven dry testing. The two common types of meters in use are the resistance meter and the capacitance meter. Meters use changes in electrical properties caused by the wood to provide an estimate of the moisture content. Oven dry testing requires a set of scales and an oven from which the moisture content is determined from the change of mass as the sample dries.

Measurements by different methods

In any piece of seasoned timber the MC is likely to vary down the length of the piece and from the outer surfaces (case) to the centre (core). Some methods of measurement are able to measure case-to-core differences while others can only measure the average MC of the board. This can be an important consideration when choosing a measuring method as case-to-core variations or the difference between upper and lower case may need to be determined. In other instances, it may be important to gain many measurements quickly in order to gain an appreciation of the average moisture content. In cases of dispute, accuracy may be of prime importance.

Resistance meters measure the highest moisture across the exposed ends of the pins whereas capacitance meters measure an average through the piece. Oven dry testing measures the average MC of the sample placed in the oven; by cutting the sample up into applicable smaller pieces, case and core moisture contents can also be determined.

The three common methods of measurement, including their application, benefits, any limitations and accuracy are described below.

Oven dry method

When is it used?

- Oven dry testing is often carried out where there are variations in the MC of the final product.
- It can have a significant affect on the performance of the product. In case of disputes, Australian Standards generally refer to this method as it provides measurements that are more accurate and reliable. For some products, such as preservative-treated timber or particleboard, it is the only method recommended.
- Manufacturers of board products often undertake oven dry testing as a check in the manufacture of their products.
- A number of organisations have the appropriate testing equipment and contract out these services.

Testing equipment and facilities

- The equipment required is an accurate electronic digital scales (+/-0.2 grams) and a laboratory oven that is able to maintain a temperature of 103°C ± 2°C.

Oven dry moisture content measurement.

Resistance meter

Principle of operation

The electrical resistance of timber reduces as the moisture in timber increases. These meters measure the flow of electricity between two pins, where the timber acts as an electrical resistor between the pins. The scale on the moisture meter is graduated to read MC. Wood temperature affects the readings, so wood temperature above or below 20°C, requires correction to the reading. Temperature correction, if not already taken care of by the meter, is applied before species correction.

Species correction is necessary because two different timber species at the same moisture content may not have the same electrical resistance. Meters are generally set up relative to Douglas Fir (Oregon) and corrections are applied for other species.

There comes a point where the moisture in timber is so low that the resistance is difficult to measure accurately or, on the other hand, sufficiently high that the resistance does not change greatly and is prone to greater errors. These meters generally provide reliable results between 6% and 25% moisture content.

Types of meters

A wide variety of meters is available. All have two pins that are used to penetrate the timber, but the pins may vary in length from about 6 mm up to 50 mm. The longer pins are often insulated up to the pointed ends to prevent surface moisture effects from interfering with core measurements. Those with longer pins are also usually of the 'sliding hammer' type, which provides a means of driving the pins into the timber. Meters with longer pins are preferred where MC is required from deeper into the timber to gain a better understanding of the moisture profile and gradient. The sophistication of the meters varies greatly in terms of features such as in-built temperature correction, pre-programmed species calibration and depth indication. Many of the meters now come with a calibration box.

Using resistance meters

- The calibration of the meter should be checked prior to use. This is usually done with a test calibration box that contains electrical resistors that correspond to the moisture contents specified on the test equipment.
- Measurements are taken in clear timber at least 400 mm from the ends of boards.
- Some meters require measurements to be taken with the pins running down the length of the board; with others the pins are to run across the board's width (check the manufacturer's manual).
- The pins are driven to the desired depth. As case and core measurements can be significantly different, meters with short pins may require boards to be cut and the pins inserted in the end grain to provide a better estimate. In high-density timbers, holes may need to be drilled for the pins.
- The pins need to be in firm contact with the timber, otherwise low readings may occur.
- Readings should be recorded to the nearest 0.5% and read shortly after penetration.
- Each reading is to be corrected for wood temperature first (provided this is not done automatically) and then for species (providing the species has not been set on the meter).
- Refer to AS/NZS 1080.1 for temperature and species correction factors.

Limitations, accuracy and precautions when using resistance moisture meters

When using moisture meters, a common-sense approach is necessary. Each reading should be evaluated and, if not as expected, the reasons for this should be investigated. The meters generally provide a reasonable estimate of the moisture content to ±2% in the measuring range from 8% to 25% and, as stated above, readings should be recorded to the nearest 0.5%. There are a number of factors that require consideration when using these meters:

- Measurement necessitates damaging the surface of the timber.
- The method is conducive to only taking a relatively small number of sample readings.
- Readings near the board surface can be significantly different from the core.
- Low battery can cause low readings in high moisture content material.
- Uncertainty over the species can make species corrections difficult.
- Species such as Brush Box have high species correction factors and are prone to greater error.
- Use for extended periods in high-humidity environments can raise meter readings.
- Meters only read the wettest part that the exposed surfaces of the pins are in contact with.

- Surface moisture can provide artificially high readings not reflecting wood moisture content.
- Salt water or any preservative treatment salts can affect meter readings and will usually raise them.
- Electrical wiring in walls can affect the readings.

If meter readings are not in line with what is expected, oven dry testing may be needed to more accurately estimate the moisture content.

Capacitance meter

Principle of operation

These meters measure an electrical property called the 'dielectric constant'. An electric field produced by the meter and the presence of the timber on which the meter is positioned, form a 'capacitor' type of arrangement. The electric field can penetrate deep into the timber but meter readings are biased toward moisture in the surface layers. Both the MC and the density of the timber affect this electrical property. The effective range of capacitance meters is from approximately 0% to 30% MC.

The more sophisticated meters can be adjusted for timbers of different densities. Cheaper meters do not have density compensation and corrections to their readings must be applied based on the density of the species being tested. Such meters are usually preset to be more suited to softwoods and lower-density hardwoods and this can cause limitations with higher-density species (i.e. large correction factors are necessary).

Types of meters

Features in capacitance meters may include settings for timber density (or specific gravity) and timber thickness as well as the ability to store readings and apply some statistics to the results. It is necessary to ensure that the meter is going to meet your specific needs and, if being used with higher density hardwoods, timber density (or specific gravity) adjustment must be considered.

Using capacitance meters

- The appropriate meter settings for density and board thickness, etc, should be applied and the meter checked for calibration.
- It is necessary to obtain from the meter supplier the figures applicable to the meter being used.

Species average densities at 12% moisture content can be obtained from numerous Australian Standards such as AS 1684.2 and AS 1720.2 as well as the grading standards.

- Measurements are then taken in clear timber, away from knots, etc.
- Some meters require measurements to be taken with the meter in a particular orientation on the board (check with the manufacturer's manual).
- The plate of the meter must be in firm contact with the board before a reading is taken.
- Readings should be recorded to the nearest 0.5%. If no density (specific gravity) settings are available then these meter readings need correcting.

Limitations, accuracy and precautions when using capacitance moisture meters

As with resistance meters, common sense must prevail: investigate and evaluate readings when they are not as expected. Providing the density is accurately assessed, these meters also provide a reasonable estimate of the average MC in a board up to about 25%. Again there are a number of aspects that need to be considered when using these meters:

- Readings can be taken very quickly within a board or in a number of boards.
- The meters do not damage the surface of the timber that is being measured.
- Within species density variations can be quite high, particularly between mature and young growth material. This can result in significant variation in meter readings.
- Estimating the correct density adjustment can be difficult, particularly if the meter is being used on a wide range of different timbers.
- Density (specific gravity) information for Australian species relating to specific meters is not well documented.
- Difficulties with setting density (specific gravity) adjustment often reduces field measurement accuracy.

- If no timber thickness adjustment is provided, thicker pieces at the same moisture content are likely to read high.
- Any gap between the meter and the board (e.g. a cupped surface) will cause lower readings.
- Framing raises meter readings where exposed timbers cross (e.g. softwood floor over hardwood joists).
- The presence of salts (either from salt water or preservation treatment) will cause readings to be higher.
- Readings are also considered to be less reliable with Brush Box.

Again, if readings are not in line with what is expected, oven dry testing may be needed to more accurately estimate the moisture content.

A4 Assessing Timber Moisture Content for Conformity

Australian Standard/New Zealand Standard 1080.1 – Timber – Methods of Test – Method 1: Moisture content – outlines a procedure for moisture content acceptance testing of timber using a resistance moisture meter. For full details the standard should be referred to.

Measuring the Moisture Content of Treated Timber, LVL, OSB, Plywood and Particleboard – Meters do not provide an accurate and reliable measure of moisture content in these materials. Use the oven dry method to determine the moisture content of these materials.

A5 – References

Standards Australia

AS/NZS 1080.1 – Timber – Methods of Test – Method 1: Moisture content

AS/NZS 4787 – Timber – Assessment of drying quality

B

Appendix B – Site Assessment Tools and Laboratory Evaluations

B1 Some Tools for Site Inspection and Assessment

Moisture meter: A meter with a hammer probe and insulated prongs as shown below is very useful to determine on-site moisture contents of solid timber products.

Pocket knife, probe, battery drill, drill bits and augers: Use these tools to assess the extent of mould and stains versus decay and decay depth in timber.

Hole saw: Very useful for taking small samples of sheet timber products such as flooring, bracing and webs in 'I' beams. The thickness of the small samples can be measured with vernier calipers and compared to original manufactured thickness and they can also be wrapped in plastic on-site and taken away for oven dry moisture content measurement.

Vernier calipers: Measure the thickness of sheet materials and other timber dimensions including gaps, etc, accurately with vernier calipers.

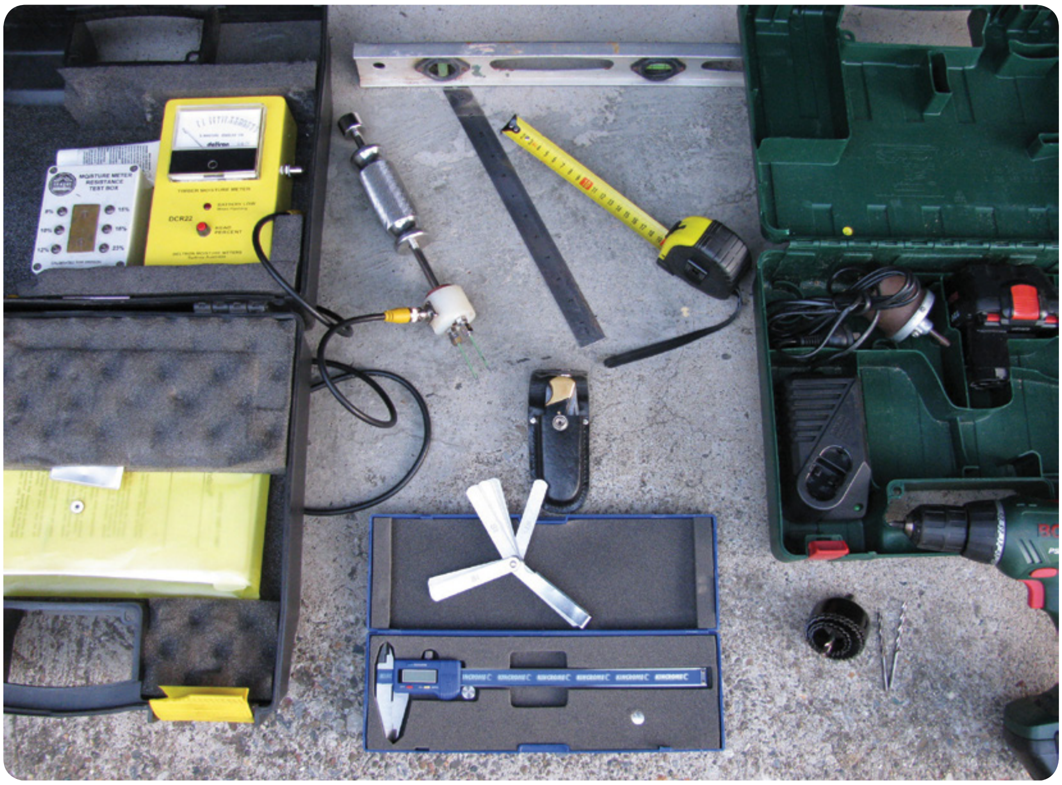
Feeler gauges: Valuable for assessing the width and depth of cracks and splits, such as may occur in solid or laminated beams or ply products.

Tape: Use for general measurement.

Spirit Level/Straight Edge: Plumb and level can be checked and they also useful as a straight edge to assess deflections between points of supports and also edge swelling in sheet products, etc.

String line: Useful for assessing out of straightness over long distances.

Compass: It is usually important when undertaking site inspections and reports to be able to determine north. This assists with recording site locations of measurements and also can aid in understanding assessment issues that may arise on-site between one part of the building and another.



Typical range of site assessment tools.

Site notebook: Record findings on-site such as locations, measurements, sketches, moisture readings, etc. Don't trust your memory.

Digital Camera: As for site notebook. These will save a heap of time and may negate need to re-visit sites if some details are forgotten.

Ladder, if required: To enable getting up close for visual inspection.

B2 Off-site Testing and Laboratory Evaluations

Where it is necessary to undertake more detailed evaluations, there are numerous industry bodies, government agencies, private companies and individuals and universities that can provide these services on a commercial basis. These services include:

- species identification
- timber treatment analysis
- termite management assessment and remedial treatment
- moisture content assessment
- mechanical properties testing and evaluation
- glue-line bond evaluations.

Further Advice and Valuable Information

Queensland Reconstruction Authority – www.qldreconstruction.org.au

Wood Solutions – www.woodsolutions.com.au

Engineered Wood Products Association – www.ewp.asn.au

Australian Timber Flooring Association – www.atfa.com.au

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Finishing Timber Externally

Technical Design Guide issued by Forest and Wood Products Australia

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Table of contents

Introduction

Timber needs to be well detailed, carefully selected and finished appropriately to work successfully in an external environment.

Finishing Timber Externally aims to provide an understanding of the important considerations of finishing timber elements externally. 'Finishing' includes surface treatments of timber elements, securing timber elements as part of a building envelope, and designing and detailing timber elements for maximum design life.

This guide complements the *Wood Solutions Guide #5 Timber service life design. Design guide for durability*. That guide provides information on the use of bare or treated timber in many external applications including in-ground posts, decks, fences and pergolas, and should be consulted for detailed information on these uses. This guide, *Wood Solutions Guide #13*, concentrates on the finishes used with timber exposed externally in decks or as part of the building envelope, such as cladding or external joinery.

Timber needs to be well detailed, carefully selected and finished appropriately to work successfully in an external environment. This guide discusses the material, finishing and fastening factors important to the in-service performance and longevity of external timber elements. It addresses using 'bare' timber externally in a contemporary context. It includes:

- a basic introduction to timber as a material;
- guidance on the wood products available and the external applications for which they are suited;
- information on selecting an appropriate finish, whether an applied finish or bare timber;
- an overview of finishing systems available including application and maintenance;
- fasteners;
- a summary checklist for the appropriate selection of finishes; and
- species information.

The information provided on applied finishes in this guide is representative of the suite of products available at the time of publication. System manufacturers should be consulted for more detailed information on specific products.

Figure 1: Bare timber used externally in a temperate climate.

1

Material basics

1.1 Introduction

This section provides an overview of how the natural characteristics of wood influence the timber used externally.

Timber is a sustainable material when it is obtained from trees that are grown and harvested as part of a managed and renewable cycle. This cycle can be certified through schemes such as the Australian Forest Certification Scheme or Forest Stewardship Council. These certification schemes require external auditing of forestry and supply-chain practices against internationally recognised standards to ensure sustainable practices are adopted. Timber used should be from a certified source.

Trees absorb carbon dioxide as part of the growing cycle which is sequestered in the converted timber or wood products. The energy required to convert the tree into a construction material is low compared to the energy required to obtain other common construction materials such as cement or steel. Therefore, timber is a material with both low 'embodied energy' and low 'embodied carbon'.

Figure 2: Native regrowth forest.

1.2 Timber characteristics

The physical properties of wood vary along the grain fibres or across them, radial to the log centre or tangential to the growth rings.

The cells that form the grain of the wood are like long hollow tubes that run up the trunk of the tree. The cellular structure influences the timber's character. The physical properties of wood vary along the grain fibres or across them, radial to the log centre or tangential to the growth rings. The character of timber obtained from a tree also varies with the species of the tree, the environment in which the tree is grown, and the location within the tree from which the timber is obtained.

Figure 3: Growth rings in pine glulam.

1.3 Moisture in timber

All timber contains some moisture. The moisture content (MC) – the amount of moisture in the wood at a particular time – is defined as the mass of water in a piece and is expressed as a percentage of its oven dry mass.

Timber freshly converted from a tree is 'green'. At this point, its MC is above the point at which moisture is saturating the timber cell walls. Typically, the timber would be dried or 'seasoned' to a moisture content aligned with that anticipated in service – generally between 12% and 18%. Drying timber increases its value and versatility by improving its dimensional stability, strength, stiffness, durability, insulating characteristics and workability.

After it has dried to service conditions, timber loses or gains moisture to be in equilibrium with its surrounding environment, shrinking with moisture loss and expanding with moisture up-take. The rate of moisture ingress or egress varies between species and whether the timber is coated. Most coatings are impervious to water but allow the transmission of water vapour. The ingress and egress is fastest through the end grain. Coatings applied to timber faces (other than end grain) should have balanced moisture permeability to avoid exacerbated distortion issues associated with differential drying. Shrinkage in-service may be as high as 12% of the section width or depth if timber is used green.

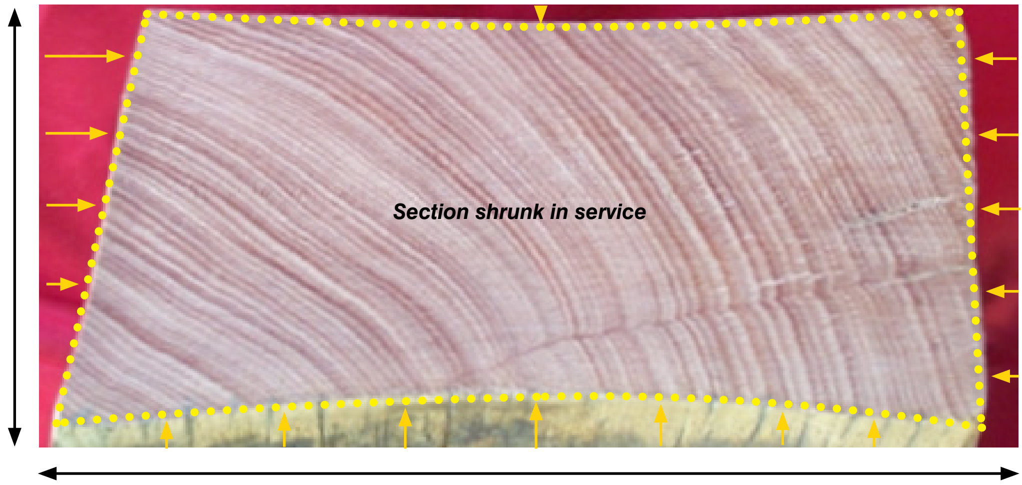


Figure 4: Shrinkage in a large unseasoned section.

On-going dimensional change of an installed element as a result of regular environmental changes is an inherent property of timber. Accommodating in-service movement is critical to the successful use of timber in external applications. These changes are predictable and the responsibility for accommodating them in external applications rests with:

- the designer/architect/specifier to ensure the material and its specified moisture content is appropriate for the application and the predicted movement in service can be accommodated;
- the contractor during assembly, site storage and installation to ensure the timber is protected and its moisture content at the time of installation is within the anticipated range; and
- the building user by following best practice maintenance procedures for the adopted external finishes.

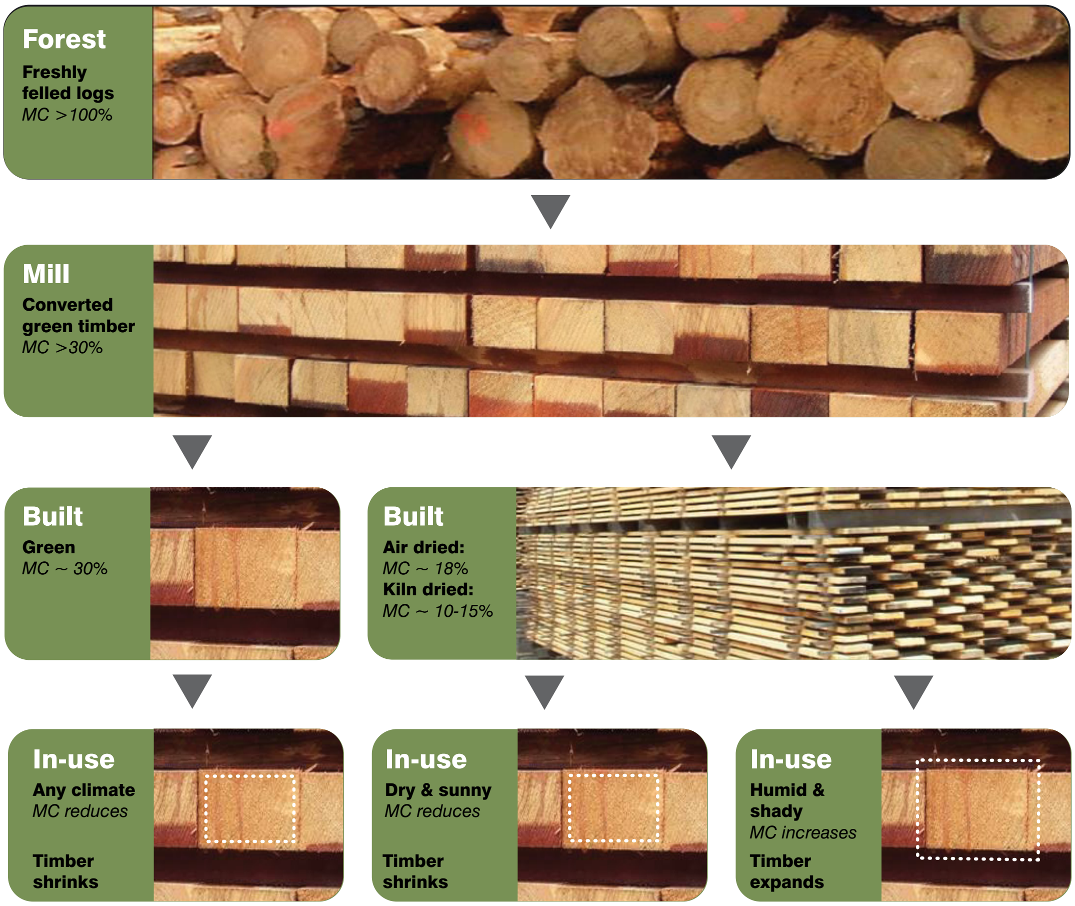


Figure 5: Changing moisture content through production and use.

2

Timber products

2.1 Introduction

This section provides a summary of the timber products available for use externally. The characteristics of each product influence their uses in external applications and suitability to produce a finish substrate or for use bare. The table below presents the most common products and comments on suitable uses, finishes, grades, species or other factors. Further information can be found from state Timber Associations, the Engineered Wood Products Associated Australasia (EWPAA), or product manufacturers.

Figure 6: Stained and coated external plywood cladding.

2.2 Timber Products Summary

Product	Uses externally	Finishes	Species/Grade	Comments
Round pole 	Canopies, bridges, retaining walls, telegraph/power poles, piles, piers, wharfs, temporary structures.	Used with penetrative treatment to low durability sapwood or untreated if a naturally durable species and the sapwood is removed.	De-barked or peeled/shaved. Species vary. Available in many stress grades. Refer AS1720.1 Section 6.	Sizes vary. Most readily available up to around 350mm diameter from forestry process. Care required to avoid splits or 'shakes'.
Solid Timber 	Structural elements, horizontal or vertical cladding, external joinery, decking, fences, furniture.	Finished with paint, varnish, stains and oils, or left bare. Preservative treatments can be used.	Graded structurally in F-grades from around F5 to F17, MGP grades, or appearance grades. See section 9 for common species data.	Size varies if sawn or machined. Decking and weatherboards usually 19mm thick and up to 175mm wide.
Glue-laminated timber 	Structural elements. Should be used in 'sheltered' locations with full flashing and surface protection.	Usually clear or translucent varnish applied, though can be painted. Preservative treatments can be used.	Structural grades GL8 to GL18. Visual characteristics usually determined by structural grade required Typically non-durable species.	Made up of small timber elements glued together. Length usually limited by transportation.
Plywood 	Cladding in large panels or cut into strips as weather boards.	Painted or varnished, or can be used unfinished if durable species and adhesives used.	Range of grades from low durability, low quality to durable exterior and marine plywood. Type A and B bond required for external use.	Panels made from veneer peeled from logs. Dimensionally stable. Common sizes 1.2m x 2.4 or 3.2m sheets. 7, 12 or 18mm thick.
Laminated veneer lumber 	Structural elements. Should be used in 'sheltered' locations with full flashing and surface protection.	Usually a translucent varnish or paint applied. Available with factory applied termite protection	Peeled, low durability plantation softwood with bond Type A.	Size varies by manufacturer. From around 35 x 90mm to 75 x 600mm.

3

Factors affecting the selection of finishes

3.1 Introduction

This section provides guidance on selecting appropriate finishes based on considerations of project performance requirements, site conditions, and timber characteristics, including the use of preservative treatments. Sources for more detailed information on each of these influencing factors are included in the relevant sub-sections below.

3.2 Finish performance requirements

The choice of finish will be driven by aesthetic requirements along with a compromise between the higher initial capital costs associated with higher-quality products and the higher ongoing maintenance costs associated with with lower-quality products and details.

For a given project, the design team should develop a preliminary strategy for finishing external timber elements such as cladding, external joinery and decks using information provided in this guide. Designers should consult *AS/NZS 2311 Guide to the Painting of Buildings* and seek advice from a manufacturer of appropriate finish types to develop a detailed specification containing the selected finish product type, substrate preparation, section preparation, priming, number of coats for different elements, and maintenance.

The choice of finishing system and timber species to be used will typically differ between vertical envelope elements, external joinery and decking because the level of exposure, cost and ease of replacement and amount of abrasion varies with each.

Developing a specification for an acceptable design life of an element should be developed with the design team and clients on a project-by-project basis considering ease of access, cost of replacement and likely building refurbishment intervals. The design life for external cladding element of a house might be as low as five years if access is easy and cost of replacement is relatively low. If access is difficult and replacement is expensive then the elemental design life of the cladding should match that of the building.

Figure 7: Painted plywood cladding, varnished timber joinery.

3.3 Timber

The characteristics of the timber used as a substrate for finishes or as a bare, exposed element has significant influence of the choice and subsequent performance of the finished element in service.

3.3.1 Substrate influence on performance

The characteristics of the timber used as a substrate for finishes or as a bare, exposed element has significant influence of the choice and subsequent performance of the finished element in service.

Timber characteristics which affect the performance of the applied finish include:

Species – The performance of different finishes varies with the species and density of the timber onto which the finish is applied. Consult finish manufacturers for detailed information on the varying performance of their products with different species.

Surface texture – Smooth surfaces offer better substrates for painting than rough surfaces. Dressed timber offers a better performance than rough-sawn timber for film-forming systems such as paints. Rough sawn timber can be used with penetrating systems such as oils and stains.

Moisture content – Seasoned timber (10 to 18% MC) provides a more stable substrate than green timber, reducing problems of cracking associated with movement of the timber under a coating. Moisture egress associated with in-situ drying of green timber can lead to blistering of finishes with low vapour permeability such as paint, so stains and oils are best adopted if the timber is green or has a high moisture content when installed and coated.

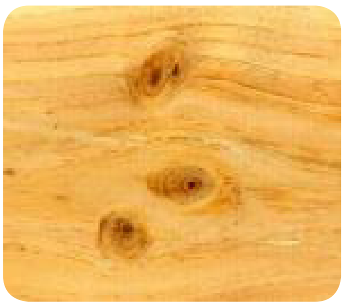
Section profile – Section edges should be arrissed or rounded to prevent concentration in coating stress for film-forming finishes. For film-forming systems such as paint, sections adopted should be as dimensionally stable as possible. Quartersawn sections are more stable then backsawn sections.

Material features – The heartwood of timber has a higher natural durability than sapwood but is harder to treat with impregnated treatments. Timber features or 'defects' will affect the finish's performance. Gum pockets can lead to resin exudation and staining unless pre-treated and sealed. Aromatic oils can lead to drying retardation and staining if surface oils are not removed. Knots can cause premature cracking and staining of the finish unless treated with knotting varnish or the manufacturer's recommended treatment. Bark left on the piece can lead to premature failure of all film-forming finishes if not removed. Extractives may cause topcoat discolouration or blistering unless the surface extractives are removed with a solvent wash prior to priming.

Surface checking –The timber grain fibres can become separated as the timber dries and shrinks, and splits or checks form on the surface. Surface checks generally have minimal effect on the structural performance of elements (unless at a critical connection) but may affect the integrity of finishes. Providing a coating which reduces the rate of shrinkage can help prevent surface checking.

Surface check

Knots



Gum vein

Figure 8: Common material features affecting finishing.

3.3.2 Weathering

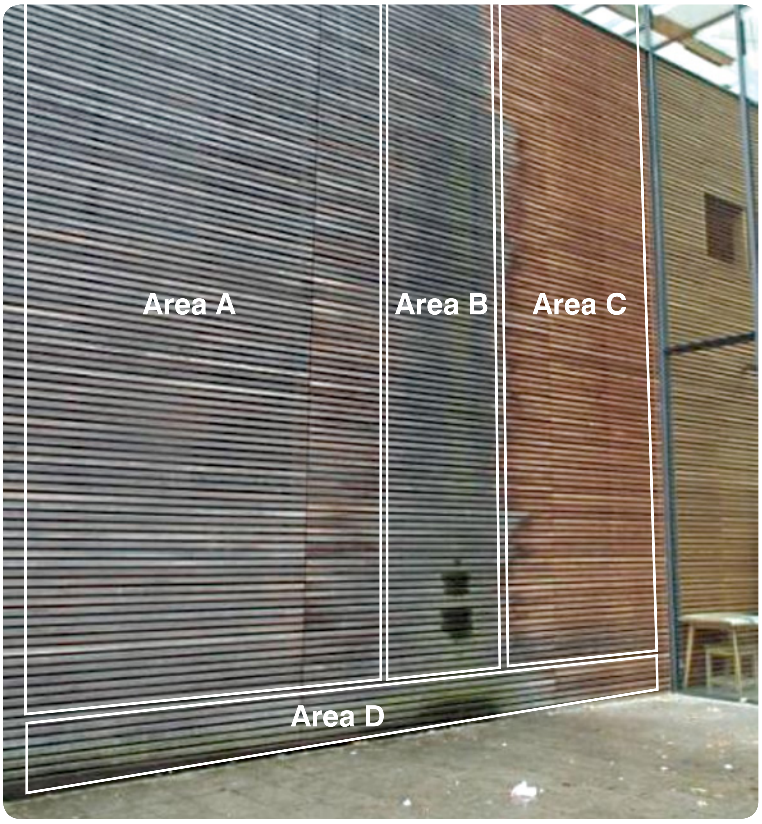
Weathering is the greying and minor cracking of a timber surface caused by light, dust or recurrent wetting and drying.

In mild or temperate climates, weathering is a slow process and would not typically lead to sufficient degradation to leave an element unserviceable in a normal design life. In harsher climates, such as the tropics or subtropics, weathering can be severe and lead to early degradation of the timber or finishes, such as checking, splitting and distortion of the timber.

Weathering affects appearance, the performances of finishes and eventually the decay rate, as water retained in any indentations in the surface of the timber or under any fractured finishing coat can nurture the growth of fungi.

Figure 9: Weathered, grey surface adjacent to unweathered surface.

Weathering is often considered a desirable attribute in building facades. However, care must be taken to ensure any differential weathering patterns associated with overhangs and sheltering are considered



Area A
Exposed: weathering to a grey colour

Area B
Run-off: biological deterioration at wettest part

Area C
Protected: remains close to original colour

Area D
Splash-back: biological deterioration with splash-back from ground

Figure 10: Differential weathering across a façade.

The greying of bare timber associated with weathering is often considered a desirable attribute in building facades. However, care must be taken to ensure any differential weathering patterns associated with overhangs and sheltering are considered. Figure 10 shows a façade undergoing several distinct regions of weathering and deterioration.

3.3.3 Durability

Timber's resistance to hazards

The long-term performance of timber finishes in external applications is influenced by the durability of the timber, whether used as bare timber or finished with an applied system. Timber resists decay and insects naturally or with the assistance of added preservative treatments or coatings.

The natural durability of a piece of timber – its resistance to decay without treatment – is a characteristic of the species. Timber species are rated in durability classes 1 to 4 for exposed in-ground contact and exposed out-of-ground contact in *AS 5604-2005 Timber – Natural durability ratings*. Class 1 is the most durable with design life greater than 40 years; class 4 is the least durable with design life as low as zero years. Species data sheets included in section 9 present the durability classes for commonly adopted timbers. More information can be found in *Wood Solutions Guide #5 Timber service life design guide*.

Timber's natural resistance to decay and insects can be enhanced by adding preservative chemicals which are a combination of insecticides and fungicides. Preservative treatments are impregnated into the timber by soaking or under pressure at the sawmill or secondary processing facility.

AS 1604-2010 Timber – Preservative-treated – Sawn and round identifies the degree of hazard present for the timber. Timber that is outside and above ground is categorised as Hazard Class H3, whether it is under the shelter of eaves or subject to full exposure of sun and wind. Treatment requirements are specified based on the Hazard Class present. For example, low-durability timber can be treated to H3, meaning it is suitable for use in any location outside above ground provided it is appropriately detailed.

AS 1604-2010 specifies the requirements for preservative treatment necessary to achieve a defined level of protection for the Hazard Class including the penetration and retention of chemicals in the timber. Not all timber can be successfully treated to the penetration or retention level required by AS 1604 using currently available commercial processes. Generally, the sapwood of all species can be treated to H3 but the heartwood of most species resists consistent treatment because the preservative cannot penetrate into the timber sufficiently. The preservative treatment is compromised if the section is cut. Exposed ends of cut treated timber should be dipped in preservative to maintain the envelope protection.

3.3.4 Bushfire

The choice of applied finish or timber species used externally may be governed by the required performance in bushfire. External timber elements are required to achieve certain bushfire-resisting performance in *AS 3959-2009 Construction of buildings in bushfire-prone areas* for a given bushfire attack level (BAL) which is determined on a project specific basis. In AS 3959 Appendix E, timbers are classified as naturally bushfire resisting or able to provide certain levels of resistance based on the density of the material. Alternatively, timber can be treated with intumescing paint or impregnated treatment to achieve bushfire-resisting properties. *Wood Solutions Guide #4 Designing for Bushfire* contains more detailed information.

Figure 11: Sheltered bare timber.

Figure 12: Bare timber shingles.

The level of exposure of the element to hazard is influenced on a regional scale, a local scale and a building scale.

3.4 Site environment

The environment surrounding the timber element defines the exposure of the element to hazards, and so influences the choice and detail of an appropriate finish. The level of exposure of the element to hazard is influenced on a regional scale, a local scale and a building scale.

3.4.1 Exposure

Climate conditions influence the level of moisture, humidity, heat and sunlight that an element has to resist. This affects the performance of the timber, embedded fastenings and any applied finishes. Generally, the timber exposed to a climate that is regularly damp or wet will decay faster than timber in a dry climate. Moist and warm climates further accelerate the decaying process. ***Wood Solutions Guide #5 Timber service life design guide*** defines four regional climate zones, shown in Figure 13. The zones consider the regional environment to provide an indication of decay potential for above ground timber and the severity of environment a finishing system must endure in service. ***Wood Solutions Guide #5*** provides typical service life for different forms of construction with different treated and untreated species in these zones.

Local site conditions such as the slope of the land, the surrounding vegetation and the proximity of lakes or the ocean modify the local climate, potentially reducing or increasing exposure to rain, wind, sunshine and persistent moisture, and can introduce additional hazards affecting finishes. The south side of hills in temperate, wet climates will generally be damper than the north side and more conducive to decay. Proximity to the sea, especially salt spray near the ocean, can significantly influence the performance of fasteners and coatings.

The position of an external timber element in the building also affects its durability and the durability of finishes. Elements on the south side of buildings are generally protected from direct sunlight. In hot climates, this protection can significantly increase the service life of finishing systems. In cool and wet climates, the regularly higher moisture content of the timber on the south side of the building can potentially expose it to increased decay.

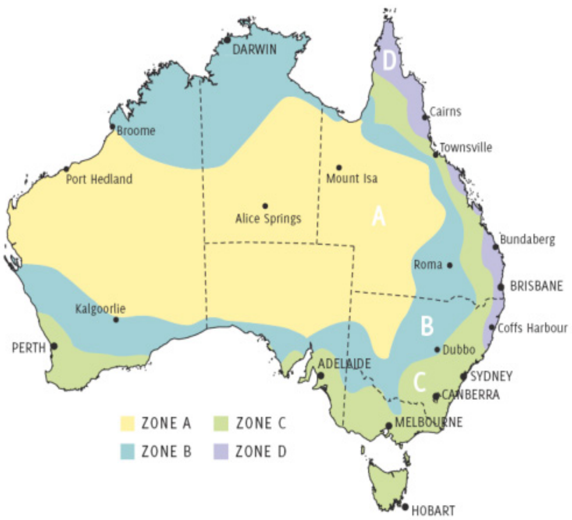


Figure 13: Above-ground decay hazard zones. (Zone D has the highest decay potential.) Source: Wood Solutions Guide #5 Timber service life design guide

3.4.2 Biological deterioration

Fungal attack can occur if the timber's moisture content is maintained above about 20% and the temperature is between 5° to 60°C. Fungal attack will lead to decay of the timber, which compromises the durability of subsequently applied finishes and reduces the service life of bare timber elements.

The temperature on the outside of a building is hard to control, but it is possible to limit the moisture content to under 20% by shedding water, keeping moisture out of the joints and allowing wet timber to dry out. Decay can occur on any surface of timber but tends to attack the end-grain of any unprotected element most vigorously. Absorption through the end grain of the element can be much quicker than through the surface grain and the higher moisture content encourages fungal growth. The rate of end-grain absorption can be reduced by coating the timber.

3.4.3 Resistance to chemicals/pollution

Finished timber elements exposed externally may be subject to high levels of pollution from adjacent traffic or industrial process. Timber is resistant to all but the strongest alkalis and acids (pH>10 and pH<2). Most pollutants of levels acceptable to humans will be unlikely to affect the timber, accept for the accumulation of dirt and discolouration. Guidance is given on the performance of finish types in the summary tables in section 6. However, seek advice from manufacturers of finishes for the performance of their products in highly polluted or unusually acidic or alkaline environments.

Adhesives used for wood products such as glulam and plywood are typically robust enough for the majority of common applications. However, seek specialist advice from the manufacturer or the Engineered Wood Products Association Australasia if the site in which the timber product is to be used has an extreme ambient environment.

3.4.4 Resistance to abrasion

Timber and finishes used for trafficked elements such as deck boards are required to resist abrasion. The Janka hardness is a measure of the resistance of an element to indentation and can be taken as an indication of the resistance to abrasion. Janka hardness values are included for species summary sheets in section 9. For commercial flooring, a Janka hardness of greater than 7 kN is recommended. Abrasion resistance can be aided by applying the correct finishing system or additive as part of an overall finishing system. A qualitative guide to abrasion resistance of different systems is given in the product summary sheets in section 5 and further advice can be obtained from the manufacturers.

3.5 Selecting timber and finishes appropriate for the conditions

The durability of the timber and finishes is affected by the hazard presented by the surrounding environment, the resistance of the timber to decay and weathering, the arrangement of species, the quality of assembly and any finish or treatment on the timber.

Australian standards allow the consideration of durability, exposure, and detailing as a whole. For example, *AS 2047 – 1999 Windows in buildings – Selection and installation* suggests that for any given project regional advice can be obtained from state forest authorities or timber industry associations, but that generally timber windows may be constructed of either:

- Durability Class 1 or 2 timber;
- timber treated in accordance with AS 1604–1997; or
- any durability class, provided that it is protected from ingress of moisture by appropriate joint details, and either the application of a protective coating or installation under a protective shelter, such as a verandah.

AS 1684.2-2006 Residential timber-framed construction provides guidance on the specification of structural timber elements for sub-classes of exposure within different hazard classes. Several categories are suggested within Hazard Class H3 (above ground external) to refine the possible elemental durability and treatments specified. For example, durability class 1, 2, 3 or 4 timbers can be used externally above ground if protected by an eave or overhang, assuming the overhang protects elements within 30° to the vertical, and they are well detailed, painted or stained and maintained.

Matching the hazard present to the durability of timber with the design service life is essential in finishing timber externally. Table 1 provides the anticipated service life of bare timber elements in an above ground exposed cladding application. Information in the table is derived from *TimberLife Educational Software V1.0* available from WoodSolutions.

Table 1: Anticipated service life

Exposure zone *See Figure 13*	**Above ground durability class**			
	1	**2**	**3**	**4**
Zone A	62 years	51 years	30 years	17 years
Zone B	51 years	42 years	25 years	14 years
Zone C	41 years	34 years	20 years	11 years
Zone D	36 years	30 years	18 years	10 years

Further information can be found in *Wood Solutions Guide #5 – Timber service life design guide*. Assumptions made in determining the service life include that:

- termites and sapwood have been excluded;
- elements are appropriately detailed, installed and maintained;
- element size is 10 to 20 mm thick, by 50 to 200 mm wide; and
- elements are assumed to be in continuous contact with adjacent members.

3.5.1 Detailing and designing to increase design life

For any given climate, location and project, there are simple steps in design and specification that can increase the design life of timber and finishes used externally. These generally assist by excluding or shedding moisture and protecting surfaces from sunlight.

- Provide eave overhangs and verandahs sufficient to shade the elements from the harshest direct sunlight and rain. Overhangs required for shading can be defined by regional sun paths. They are generally considered to provide shelter from rain if they project an angle of 30° to the vertical.
- Place boards with surface features such as knots in areas of lower exposure. Such features can provide weaknesses in water shedding and finish integrity.
- Adopt timber profiles with rounded arrises rather than sharp corners to promote shedding of water and reduce stress concentrations in surface finishes associated with sharp corners.
- Provide adequate ventilation to allow rapid drying of areas that do become moist.
- Use the recommended fastener size and pattern for various types of timber cladding to prevent moisture movement becoming constrained and to provide sufficient structural connectivity.
- Use vertically orientated rather than horizontal cladding. This removes horizontal ledges that can trap and retain moisture.
- Detail drip caps over doors and windows to ensure that incidental rain and moisture is shed from the joinery and does not seep into timber elements.
- Avoid or minimise joints in horizontal cladding because these typically allow moisture ingress

For any given climate, location and project, there are simple steps in design and specification that can increase the design life of timber and finishes used externally.

Figure 14 shows deterioration of a façade with differential exposure conditions on adjacent elevations. The more exposed elevation on the right faces more onerous hazards from the site conditions and is less protected by overhangs than the more sheltered facade on the left.

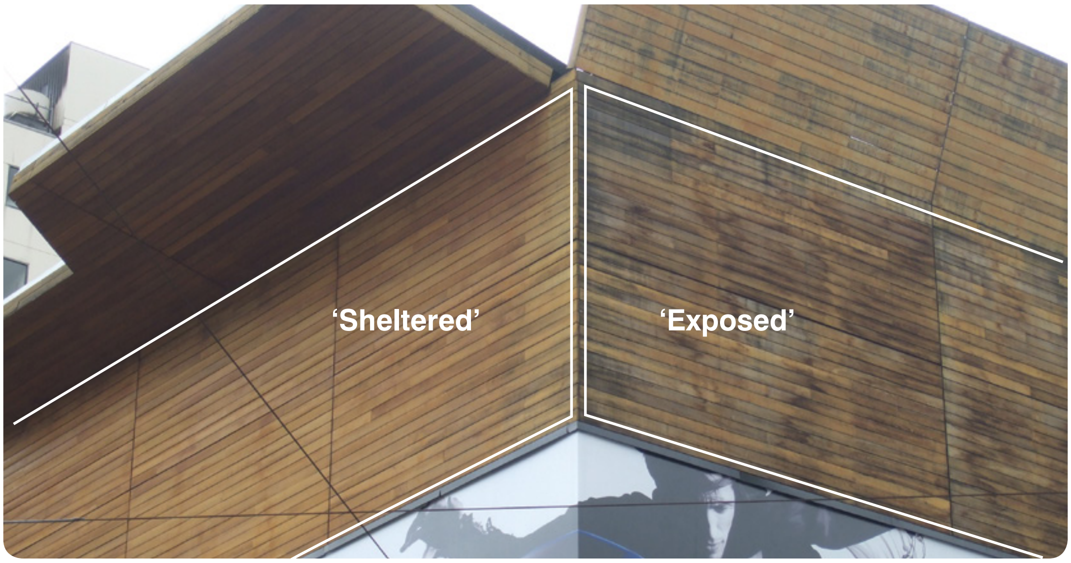


Figure 14: Differential deterioration on facades.

Figure 15 presents good practice with respect to preventing water ingress into a bare timber clad wall. A flashing is used on the upward facing elevation of the elements to protect the end grain, a clear drip space is left at the base which allows water run-off, the timber façade is lifted from the ground on a concrete plinth to prevent splash-back of rain on the ground surface, and the base of the boards are bevelled to form a drip line.

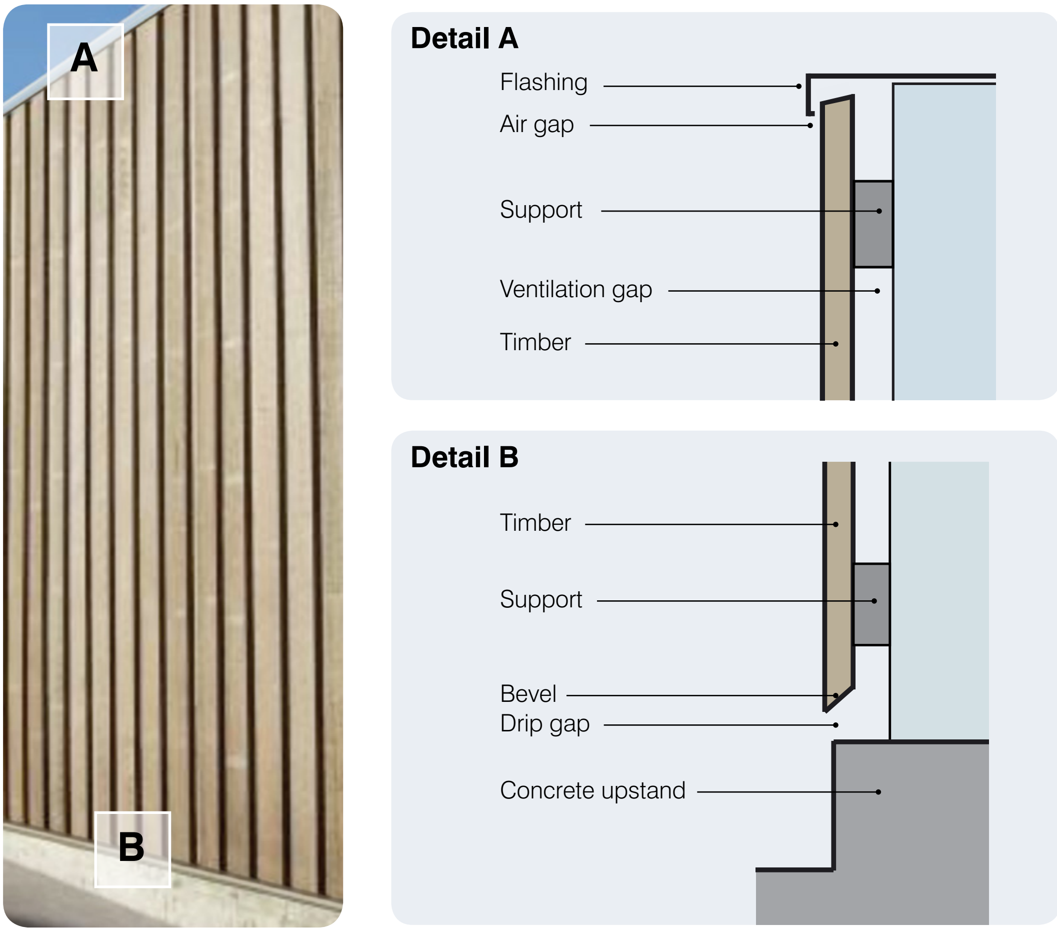


Figure 15: Detailing to avoid standing water.

4

Finishing systems

4.1 Introduction

This section provides a summary of different options available for finishing timber externally. ‘Finishes’ describes the in-service surface of the timber element and includes bare timber. The choice of finish will be influenced by the combination of factors described in section 4. The availability of finishes is both time and region dependent and so cannot be covered meaningfully in this guide. General qualitative guidance is given to the anticipated installation and maintenance costs for finishes. Quantitative costs should be developed for specific projects. *AS/NZS 2311 Guide to the Painting of Buildings*, and product manufacturers and suppliers, should be consulted for more detailed information.

4.2 Finishing system basics

All applied finishes, whether transparent, translucent or opaque, provide some degree of film or ‘coating’ on the surface and to some extent fill voids in the microscopic surface structure, penetrating the surface. Finishes are generally either predominantly film forming or penetrating, but will generally feature some characteristics of both. Film-forming and penetrating finishes vary in thickness and in the finished shape of the surface they create. Film-forming finishes appear as a distinct layer on the surface of the timber, visually creating a smooth surface. Penetrating finishes follow the contours of the timber surface, providing thicker deposits in the troughs and thinner coatings over the peaks, leading to colour variegation over the surface and emphasising the grain. Incorrect specification or poor maintenance of a film-forming finish can lead to accelerated degradation rather than protection of the timber substrate, as moisture enters through the cracked surface and becomes trapped with the timber.

Figure 16: Poorly maintained paint which is trapping moisture.

Film-forming finishes are more resistant to wear because they feature a greater film thickness, but penetrating finishes are better able to accommodate the differential movement of timber caused by moisture variations. The advantages of penetrating finishes over film-forming finishes include:

- natural appearance
- do not peel or blister
- suited to sawn textured surfaces
- do not trap moisture in timber
- more easily applied
- more easily maintained, but require more frequent maintenance.

Transparent coatings and stains are typically a combination of film-forming coating and penetrating oil with added preservatives, fungicides, and colourants. The oil improves appearance and adhesion, while the surface coating protects the timber from wear and excludes moisture. The degree of film formation and penetration varies with product and manufacturer.

Transparent coatings and stains protect the timber while the grain and texture of the timber remain visible. The preservatives and fungicides in these finishes provide some degree of protection but they are not substitutes for preservative treatment to AS1604. These finishes can shed water and can provide UV resistance, particularly with some pigmentation, but the surface of the timber can still weather. Weathering leads to cracking or peeling of the finish if exposed to sunlight over time.

Penetrating oil finishes can contain preservatives and fungicides but are generally not long-lasting in external applications, particularly when regularly exposed to sunlight. The oil may also become a food source for fungi and can eventually encourage surface mould.

Paints are opaque, film-forming finishes which protect the timber from water, sunlight and abrasion. Paints are generally applied at higher film thicknesses than stains and are able to conceal light texture in the surface of timber. As UV cannot reach the surface of the timber and break it down, these finishes last much longer than translucent coatings. Paint needs to be flexible as the timber slowly expands and contracts with changes in moisture content.

Paints are typically used in a system that includes a priming coat. Wood primers provide good adhesion to the timber and a good base for inter-coat adhesion of subsequent coats.

Most modern paint coatings for timber, including primers, are water-based acrylics. Acrylics do not have the chemical emissions commonly associated with solvent-based finishes, are easier to apply and clean up, and have a shorter recoat time. Older acrylics did not have the durability of solvent-based paints but acrylics have significantly improved and are now the preferred systems for coating external elements.

Figure 17: Painted timber doors and surrounds.

Light colours are generally more durable than darker colours because they do not absorb as much heat from sunlight.

Film-forming paints can become brittle through prolonged exposure to UV and can breakdown and flake away from the timber. The flexibility and resistance to breakdown is usually directly related to the quality of the product and of the installation. Water-based acrylic systems are typically more flexible than solvent-based systems. Light colours are generally more durable than darker colours because they do not absorb as much heat from sunlight.

4.3 Finish type summary tables

The following tables present information on six generic types of finish ordered from most to least transparent. The information presented aims to be generic but representative. Details will vary between products and manufacturers.

Bare untreated timber

Initial cost: High

Maintenance cost: Very low

Description:
A suitably durable species used without treatment or finish for cladding or decking elements. Exposure, detailing and natural species' durability has to be matched to suit particular applications. Timber can be used green or seasoned. Timber will weather over time, changing colour depending on the level of exposure. Class 1 durable species includes Blackbutt, Spotted gum, Tallow wood, and Merbau. Prefer certified timber, especially with imported species. High initial material costs.

Features:
- Timber texture remains
- Colour will change with weathering depending on exposure
- Timber MC changes uninhibited

Benefits:
- Little on-going maintenance
- Lowest environmental impact solution (depending on source of timber and quality of detailing)

Uses: All exterior elements except external joinery.

Life to first maintenance period: Little or no maintenance

Typical Performance (resistance to):

Heat	Good
Solvent	Good
Acid	Good
Mechanical degradation	Poor
Salt	Unaffected
Abrasion	Good with harder species
Alkali	Good

Typical Properties:

Gloss Level	N/A
Finish	N/A
Colour	Timber colour with gradual colour change due to weathering
Toxicity	None
VOC	None
Touch dry/recoat	N/A
Application Method	N/A
No. Coats	N/A

Precedents:




Oil

Initial cost: Low

Maintenance cost: Low to medium

Description:
Penetrating oil composed of a blend of natural and synthetic oils in combinations varying between manufacturers. Also available with added pigments which provide UV protection (pale colours provide maximum protection). Resistance to fungal and mould growth varies between products and manufacturers.

Features:
- Nourishes timber
- Timber pattern and texture remain
- Water repellent

Benefits:
- Will not crack, peel or blister
- Can be UV, mould and fungus resistant
- Can be naturally and sustainably derived oils
- Fast drying

Uses: All exterior timber including decking and rough sawn timber

Life to first maintenance period: 1-3 years

Typical Performance (resistance to):

Heat	Up to 120°C
Solvent	Resists mineral turps.
Acid	Fair
Salt	Unaffected by splash and spillage
Abrasion	Moderate resistance
Alkali	Fair

Typical Properties:

Gloss Level	Nil
Finish	Penetrating
Colour	Clear to translucent to pigmented
Toxicity	Lead free. Can be non-toxic
VOC	<665 g/L
Touch dry/recoat	0.5 hr/4 hrs
Application Method	Brush, pad
No. Coats	2

Swatches:

Clear exterior varnish

Initial cost: High

Maintenance cost: High

Description:
A tough, clear, water-based predominantly film-forming finish with possible added UV protection (depending on product). Provides a glossy surface finish while revealing grain beneath.
Cost of application usually high.

Features:
- Water based
- Non-yellowing
- 100% acrylic
- Low odour

Benefits:
- Fast drying and easy clean up
- Retains natural timber colour and grain
- Tough and durable
- Can be UV resistant

Uses: Window frames, doors and trims

Life to first maintenance period: 2 years

Typical Performance (resistance to):

Heat	Up to 70°C
Solvent	Fair.
Acid	Fair
Salt	Unaffected by splash and spillage
Abrasion	Moderate resistance
Alkali	Fair

Typical Properties:

Gloss Level	Gloss or satin
Finish	Predominantly film forming
Colour	Clear
Toxicity	Dry film non-toxic
VOC	<90 g/L
Touch dry/recoat	1 hr/4 hrs
Application Method	Spray, brush, pad
No. Coats	3 or 4 in high exposure areas

Precedents:

Pigmented exterior varnish

Initial cost: Medium to high

Maintenance cost: Medium to high

Description:
A tough, clear, water-based predominantly film-forming finish with possible added UV protection (depending on product). Provides a glossy surface finish while revealing grain beneath. Cost of application usually high.

Features:
- Water based
- Non-yellowing
- 100% acrylic
- Low odour

Benefits:
- Fast drying and easy clean up
- Retains natural timber colour and grain
- Tough and durable
- Can be UV resistant

Uses: Window frames, doors and trims

Life to first maintenance period: 2 years

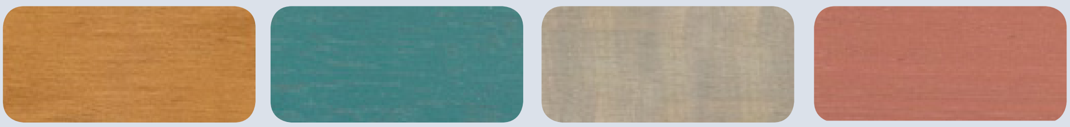
Typical Performance (resistance to):

Heat	Up to 70°C
Solvent	Fair
Acid	Fair
Salt	Unaffected by splash and spillage
Abrasion	Moderate resistance
Alkali	Fair

Typical Properties:

Gloss Level	Gloss or satin
Finish	Predominantly film forming
Colour	Clear
Toxicity	Dry film non-toxic
VOC	<90 g/L
Touch dry/recoat	1 hr/4 hrs
Application Method	Spray, brush, pad
No. Coats	3 or 4 in high exposure areas

Swatches: *Colour by manufacturer*



Precedents:

Stain

Initial cost: Low to medium

Maintenance cost: Low to medium

Description:
Penetrating stains available in many tones. Stains soak into the timber surface once applied leaving grain pattern and texture. Grey stains can be used as a temporary coating to achieve apparent weathering while timber behind weathers to grey.

Features:
- Lightly pigmented
- Water based
- Grain and texture remain

Benefits:
- Can block tannins to prevent staining
- Can be mould and UV resistant
- Slip resisting additives available

Uses: External joinery, cladding, decking and furniture

Life to first maintenance period: 3-6 years

Typical Performance (resistance to):

Heat	Softens above 70°C
Solvent	Fair
Acid	Fair
Salt	Good
Abrasion	Moderate resistance
Alkali	Fair

Typical Properties:

Gloss Level	Matt – low sheen
Finish	Penetrating
Colour	Varies with manufacturer
Toxicity	Lead free. Dry film non-toxic
VOC	<75 g/L
Touch dry/recoat	1 hr/3 hrs
Application Method	Spray, brush, pad
No. Coats	2 to 3 (more if the surface is horizontal)

Swatches: *Colour by manufacturer*

Precedents:

Paint

Initial cost: Medium to high

Maintenance cost: Medium

Description:
Opaque coloured film-forming paint for surface coating timber. Usually applied as a system with primers and top coats. Can be factory or site applied. Traditionally available in solvent or acrylic compositions. Solvent-based paints are becoming rare. Light colours tend to have a longer service life.

Features:
- Large colour range available
- Slows or prevents moisture changes in timber
- Typically oil enriched acrylic
- Can be thinned by <10% water for warm or highly absorbent surfaces.

Benefits:
- UV and mould resistant
- Water resistant
- Tannin block (but does not seal knots)
- Can be self-priming but usually used with system primer

Uses: All exterior timber including decking

Life to first maintenance period: 7-10 years

Typical Performance (resistance to):

Heat	Softens above 70°C
Solvent	Sensitive to alcohol and hydrocarbons
Acid	Dilute splash-proof
Salt	Resists salt spray
Abrasion	Good resistance
Alkali	Dilute splash-proof

Typical Properties:

Gloss Level	10 to 20%
Finish	Predominantly film forming
Colour	Any possible
Toxicity	Lead free. Dry film non-toxicxic
VOC	<65 g/L
Touch dry/recoat	0.5 hr/2 hrs
Application Method	Spray, brush, pad
No. Coats	2 to 3

Precedents:

5

Applying & maintaining finishes

5.1 Introduction

This section presents key considerations and guidelines for the application and maintenance of the various finishes. Consult manufacturers for detailed information on the use of specific products.

5.2 Site- or factory-applied finishes

Generally, site finishing provides a greater flexibility of construction process and sequence, but factory finishing provides a higher quality of finish.

The choice of site- or factory-applied finish will be determined by the finish type, the element size, type and form, and the construction process. Generally, site finishing provides a greater flexibility of construction process and sequence, but factory finishing provides a higher quality of finish.

Site

Timber cladding elements used externally may be installed bare or with a low-protection factory finish and subsequently finished in situ. Access should be provided to allow the finish to be applied in a controlled manner, following the manufacturer's guidelines. Generally, eye and skin protection should be worn, ventilation should be provided, and a respirator should be worn if spraying.

Most finishes require an ambient and surface temperature between 10° and 30°C for the duration of drying or curing time. Care is needed to ensure that the temperature of timber in direct sunlight is within this temperature range.

Figure 18: Site-applied pigmented deck stain requiring maintenance.

Factory

Some timber elements, wood-based building boards, windows and doors are supplied pre-primed or pre-finished. The quality of finish and level of protection offered can vary from a completely finished top coat to a temporary pre-primer. Timber products factory-supplied with a pre-primer temporary protection above a treatment, such as LOSP, should be completed on-site to the manufacturer's recommendations and would typically involve sanding the surfaces and re-priming and finishing.

The quality of final finish obtained in factory application for joinery elements is generally higher than that achievable with site application. The finish can be applied to all surfaces of elements pre-assembly, which provides a significant advantage in the assembly of joinery units. Care is required not to damage factory applied finishes in handling on-site. On-site repair work of damaged units is often below the standard achieved with the factory finish.

Factory pre-primed elements may be finished on-site with a compatible top coat without significant preparatory work other than cleaning, provided there is no evidence of deterioration of the workshop-applied coating.

5.3 Surface preparation

The purpose of preparing a substrate for finishing is to ensure that it will accept and retain the finish with the minimum of interference from surface contaminants or from previous deterioration.

The purpose of preparing a substrate for finishing is to ensure that it will accept and retain the finish with the minimum of interference from surface contaminants or from previous deterioration. The profile of the surface and its porosity will also influence adhesion of the paint system and its ultimate durability. The manufacturer's instructions should be followed in the preparation of the substrate and application of finishes in order to achieve the maximum service life from a product.

Any holes or depressions in the surface that may have occurred as a result of mechanical damage or are natural features such as resin pockets, knots, surface splits or checks should be scraped clean, primed and filled with a filler compatible with the finishing system to be used. Damaged or decayed sections should be cut out and replaced. The source of moisture should be located and the fault rectified. Adequate sealing, with sealants, water repellents or primers is essential to prevent moisture ingress into the end grain, but care should be taken not to seal moisture into the timber.

Salt contamination can quickly accumulate in buildings adjacent to the sea and must be washed off with fresh water and allowed to dry shortly before the start of work. Washing will be required each day before finishing if prevailing winds are carrying salt-laden air to the site.

New bare timber

The surface of timber can vary from a smooth (planed) surface to a sawn textured surface. The surface texture will dictate the final appearance when finished. The sawn or roughened (coarse sand papered) surface will give a more positive mechanical key to applied finishes but will result in a much thinner film on the surface peaks in the case of a film-forming finish which may lead to more rapid deterioration.

Timber with high moisture or resin/aromatic oil content should be allowed to weather for 4-6 weeks or until tanins and oils have ceased leaching before applying a film-forming finish. After weathering, timber should be lightly sanded, dust should be removed and the element cleaned before applying a finish.

The timber surface should be free from dust, grease, oil and other surface contaminants prior to finishing. It is better to avoid contamination of the surface rather than relying on cleaning; however, timber can be cleaned with specific timber cleaning products, water or spirit based cleaners. New and cleaned timber should be treated with a timber-sterilising solution before finishing in humid, tropical or mould-susceptible areas.

Previously finished timber

The preparation required for refinishing a previously finished surface will depend largely on the condition of the surface and the finish to be applied. In the case of film-forming finishes it will be necessary to remove either the entire film back to the substrate, or at least enough of it to provide a sound base for subsequent film-forming finishes if the previous finish is flaking, blistering, cracking or checking. In the case of penetrating finishes it may be possible to apply a new finish after simply cleaning the previous surface.

Manufacturers will typically recommend that all film-forming finishes which seal the surface should be removed back to bare timber, lightly sanded and cleaned with specific timber cleaning products. Surfaces previously stained or oiled should be lightly sanded and cleaned with specific timber-cleaning product.

Weathered, grey or mould-affected timber

Exposed timber which has weathered should ideally be sanded or dressed to a fresh surface before finishing if using a film-forming type finish. Penetrating type stains can be used after weathering without sanding on fresh timber.

5.4 Application

Individual products allow or prohibit certain application methods such as brush, roller, spray or pad. Suitable application methods are presented in the generic product sheets in Section 4, but should be confirmed for specific products. Penetrating finishes should generally be applied in the direction of the timber grain.

The effectiveness of an exterior finishing system is dependent on building a film of adequate thickness or providing sufficient finish for penetration, so overspreading of finishes is a false economy. The manufacturer's recommendations on thinning, surface preparation, number and sequence of coats, maximum spreading rates, weather conditions and temperature at times of application and drying, and time interval between coats, should be adhered to at all times.

The manufacturer's minimum recommended time should elapse between coats to ensure good adhesion. Care should be taken to ensure that the surface is clean and suitable for the application of subsequent coats if the time between coats is sufficient to allow for dirt to build up. The required cleaning interval between coats will vary depending on site conditions from daily, for highly polluted or coastal sites, to two weekly for sheltered sites.

Finishes should generally not be applied during extremely hot weather or when temperatures fall below 10°C. Foggy, misty or dusty weather should also be avoided. Work should be stopped early enough to allow for the film to dry sufficiently before adverse conditions develop.

5.5 Maintenance

It is difficult to predict the actual period from installation to first maintenance required for finishes because of varying exposure conditions of the site, the building, and within the element.

It is difficult to predict the actual period from installation to first maintenance required for finishes because of varying exposure conditions of the site, the building, and within the element. Areas subject to the highest exposure such as unshaded north-facing window sills may require remedial work sooner than the average product life span. Well protected elements may last three or four times longer than the exposed areas before remedial work is required. Regular visual inspection and cleaning is essential to identify areas of potential deterioration before the finish becomes compromised.

- Film forming finishes should be inspected for patchiness and thinning of the coating which are early signs of degradation and should be identified before the finish begins to flake or blister. An additional coat should be added in accordance with the manufacturer's recommendations.
- Penetrating finishes should be inspected for loss of colour or dryness, which will be evident at the early stages of degradation. Timber should be cleaned thoroughly and recoated in accordance with the manufacturer's recommendations.

Figure 19: Poorly maintained film-forming finish.

6

Fasteners

Inappropriate fastener choice will have a detrimental effect on the finishing of timber elements externally.

6.1 Introduction

This section presents key considerations in selecting suitable fasteners for timber elements in the external building envelope or decking. Inappropriate fastener choice will have a detrimental effect on the finishing of timber elements externally. Figure 20 shows the rapid deterioration of fasteners associated with the galvanic reaction of the fastener metal. The paint finish is blistered and stained as the fasteners corrode rapidly.

Figure 20: Rapid corrosion of poorly specified fasteners.

6.2 Fasteners

Fasteners should be structurally fit for purpose. Guidance can be provided by fastener manufacturers, the project engineer or, for smaller projects, the builder. Fasteners supporting external elements must resist suction (negative pressure) associated with wind loading, which will vary significantly from site-to-site and between regions, from negligible to very significant.

The durability of fasteners is influenced by the material from which they are made or the coatings applied to the fasteners, the species of the timber in which they are fixed, and their level of exposure. Galvanised steel or stainless steel fasteners are the most common types used externally. Certain timber treatments can lead to accelerated corrosion of fasteners due to galvanic reactions between the treatments and the fasteners. More durable fasteners are required in such circumstances. Guidance can be found in *EWPAA Technical Guide – Specification of fasteners* and *Wood Solutions Guide #5 Timber service life design guide: Design guide for durability.*

6.3 Detailing

Careful consideration of the placement, the number and the type of fastener is critical in fixing externally exposed timber. Externally exposed timber is subject to significant changes in moisture content and will move, expanding and shrinking with seasonal changes. Too many, overly stiff or poorly placed fasteners will restrain timber from shrinking and expanding with moisture content changes. This typically leads to splitting in the case of shrinkage, and buckling or local crushing in the case of expansion.

6.3.1 Unseasoned, 'green' timber

It is possible to use an appropriately durable timber species 'green' as well detailed external cladding but care is needed to accommodate the shrinkage that will occur as it dries to its in-service moisture content. Shrinkage in width and depth may be up to approximately 13% tangentially and is commonly between 5-7%. Subsequent shrinkage and expansion cycling with seasonal changes must also be accommodated in the fixing detail and the finishes. Examples of detailing of this type are shown in Figure 21 and Figure 22 where each cladding board is fixed with a single fastener, thus allowing movement to occur unrestrained by fasteners.

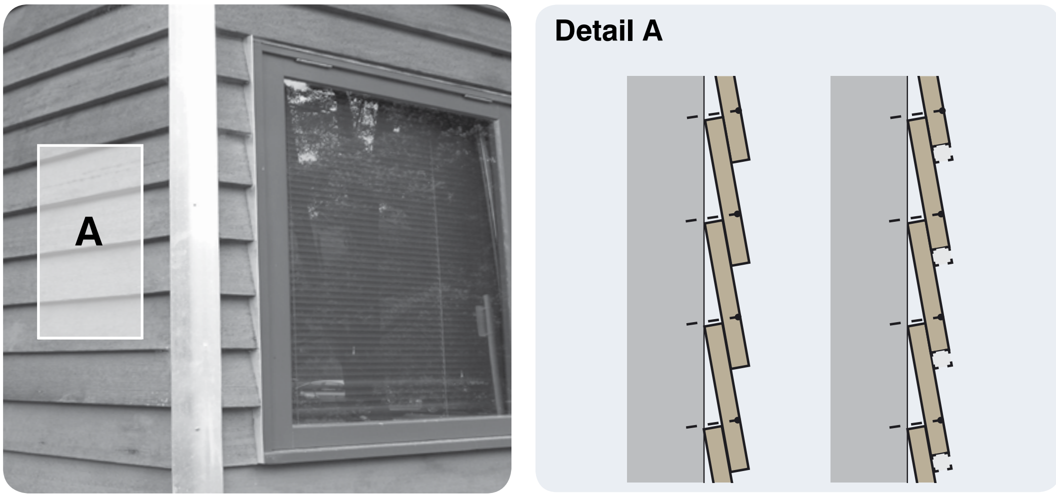


Figure 21: Detailing green timber weatherboards to allow movement.

Figure 22: Visually significant fasteners; vertical green timber cladding.

Seasoned or 'dried' timber used as cladding or decking will not undergo the dramatic shrinkage in-service that occurs with green timber.

6.3.2 Seasoned timber

Seasoned or 'dried' timber used as cladding or decking will not undergo the dramatic shrinkage in-service that occurs with green timber. However, the timber will expand and contract as its moisture content changes with seasonal variations in the surrounding environment.

Figure 23 shows a horizontally clad rain screen with semi-translucent coating and gaps between boards. A pair of stainless steel cross-head screws is used to fix the boards at regular centres along their length. The boards were dried prior to treatment and installation, so in-service movement will only be due to change in environmental conditions rather than the much larger shrinkage associated with in-situ drying. As the boards in this case are also relatively narrow, the in-service movement anticipated between the two fixings will be relatively small, so the problem of restraining the movement between the two screws is limited.

Figure 23: Visually significant fasteners, seasoned horizontal cladding.

7

Selecting a finish which is appropriate for use externally on a project requires consideration of the desired design life, aesthetic requirements, durability in regional and local site conditions, timber fasteners and connections and installation and maintenance regimes.

Finish selection summary

7.1 Introduction

Selecting a finish which is appropriate for use externally on a project requires consideration of the desired design life, aesthetic requirements, durability in regional and local site conditions, timber fasteners and connections and installation and maintenance regimes. This section presents a summary of those key considerations and provides references to relevant texts.

7.2 Finish selection summary

Establish the desired design life for the element or finish

- An appropriate design life will depend on ease and cost of replacement and maintenance.
  - An element or finish which is easy to access and cheap to replace may have a short design life.
  - An element or finish which is difficult to access and expensive to replace should have a design life which matches the overall building design life.
- A building which is likely to be frequently refurbished may have elements with a design life to match refurbishment intervals.

Determine the desired surface aesthetic

- The choice of finishing system should be compatible with the timber substrate. These two factors influence the finish quality and character.
  - Machined, dressed timber elements with an opaque paint finish will result in a smooth, uniform coloured surface.
  - Rough-sawn timber with an oil or stain will allow visible grain and texture to remain with varying pigmentation.
- The quality of the surface aesthetic achieved varies with products and species. Finishing system manufacturers should be consulted for detailed information.
- Bare timber will change colour with weathering at rates varying with exposure, regional climate and species. State-based timber industry associations should be consulted for detailed information on available appropriate species.

Design measures can be used to maximise design life

- Finished elements can be effectively sheltered by an eave or overhang at 30° to the vertical.
- Elements should be detailed to shed water with sloping top surfaces, head flashings and drip lines.
- Connections and element interfaces should be designed to allow water to drain away and for ventilation to dry any residual moisture.
- Allowance should be made in the connections, fasteners, waterproofing and applied finishes for the movement anticipated in service from changing moisture content.
- Further information can be found in *Wood Solutions Guide #5 Timber service life design*.

Determine the level of hazard present

- All elements will be hazard class H3 to AS 1604-2005 but elements can be sheltered or fully exposed within H3 category. Sheltered elements are subject to less severe hazard from UV and rain.
- In bushfire prone areas AS 3959-2009 may require the use of certain timber species or intumescing finishes. *Wood Solutions Guide #4 Designing for Bushfire* provides further information.
- Buildings in areas prone to termite attack should be designed in accordance to *AS 3660.1-2000 Termite management: New building work* which may affect the detailing of the finished building envelope elements.
- Further information can be found in the *Wood Solutions Guide #5 Timber service life design*.

Select an appropriate finish, timber section and species

- Studying local precedents will provide valuable information on finishing systems and details which have been successful in similar applications.
- Finishes feature a combination of film-forming and penetrating characteristics. Film-forming finishes provide a coating over the surface and smooth out minor surface texture. Penetrating finishes follow the surface texture and grain. See product data sheets in section 5.
- Consider the desired aesthetic, the finishing system application cost, maintenance access and cost, and required finish design life. Higher initial capital costs associated with a higher quality finishing system will generally lead to lower on-going maintenance costs.
- The selected timber species should be sufficiently durable for the application. Timber can be a naturally durable species of class 1 or 2 to AS 5604-2005, or treated to H3 of AS 1604-2010.
- The selected finish should remain serviceable during the moisture movements anticipated, based on timber species or wood product used, timber section sawing and size and fastener detailing.
- The selected finishing system should be compatible with the timber species or wood product selected, the surface texture, presence of features and preservative treatments applied.
- Further information on finishing systems can be obtained from finishing system manufacturers.
- Further information on appropriate available species can be found from the state timber industry associations.

Select fasteners appropriate for the application, timber, finish and movement

- Galvanised or stainless steel fasteners should be used for treated timber to avoid excessively rapid corrosion of the fasteners due to incompatibility. Further information can be found in *EWPAA Technical Guide – Specification of fasteners* and *Wood Solutions Guide #5 Timber service life design*.
- The design life of the fastener should match the anticipated design life of the element. Further information can be found in *Wood Solutions Guide #5 Timber service life design*.
- Extractives in certain species react with fasteners of particular material leading to rapid corrosion. Fasteners should be selected to be compatible with timber species. Further information can be found in *Wood Solutions Guide #5 Timber service life design*.
- Timber will shrink and expand in service with moisture content changes. Fasteners should be designed and specified to avoid constraining large in-service movements. A single row of fasteners parallel to the grain should be used if green timber is used or large movements are anticipated.
- Fasteners should be specified in accordance with the National Construction Code and associated standards. Structural applications should be engineer designed to *AS 1720.1-1997 Timber structures*. *AS 1684 Residential timber framed construction* should be referenced for residential construction.

Develop a detailed specification for finishing system

- A detailed specification for the selected finishing system should be developed with advice from finish manufacturers and *Species information*. Specification should include: selected finish brand, product range, colour; finish system including primer, undercoat, number of finish coats; substrate preparation; priming of joints; extra coats on sills, rails, etc; and maintenance regime.
- The specification for the timber substrate or the bare timber elements should include timber species, sustainable sourcing, timber durability class, moisture content, sawing pattern and surface finish. State timber industry associations should be consulted for more information.

Apply finishes to the manufacturer's specification

The timber substrate should be prepared in accordance with the manufacturer's instructions. Generally, timber should be clean, free from oil and grease, and free from extractives.

- The preferred method of application, whether brush, pad, roller or spray, will depend on the product used.
- Drying times between coats recommended by manufacturers should be observed. Ensure earlier coats are clean before subsequent coats are applied.

Maintain the installed system

- Bare timber elements should be inspected for signs of deterioration. Methods of ensuring water shedding and ventilation around the timber should be inspected to ensure they remain effective.
- Penetrating surface treatments should be inspected for signs of patchiness and colour-loss. Surfaces should be cleaned before additional coats are added. Finish manufacturers recommendations on maintenance and re-coating should be followed.
- Film-forming finishes should be inspected for signs of patchiness. Existing surfaces should be cleaned before new coats are added. Flaked or cracked finishes should be removed to bare timber before a new system is applied. The manufacturer's recommendations on maintenance should be followed.

8

Species information

Blackbutt, ***Eucalyptus pilularis*** — **Australia**

Name	Blackbutt
Species Name	*Eucalyptus pilularis*
Other Name	Pink blackbutt
General Availability	Readily
Source	A large hardwood common in the coastal forests of south-eastern Australia from Bega to Maryborough – native forest and plantation grown timber.

Appearance

Description	The heartwood ranges from pale cream to light yellow-brown with little difference between heartwood and sapwood. The grain is very fine and even textured. Growth rings usually visible but indistinct.

Durability

Durability Class	Outside above ground: Class 4, In-ground contact: Class 4.
Lyctis Susceptability	Not susceptible
Termite Resistance	Not resistant
Preservation	Sapwood readily accepts impregnation but the heartwood cannot be adequately treated.

Stability - Unit Shrinkage

Radial	0.18% (per 1% MC change)
Tangential	0.23% (per 1% MC change)

Physical Properties - Seasoned

Density (kg/m³)	550
Strength Group	SD5
Joint Group	JD4
Hardness (kN Janka)	3.4 (native forest material)

Early Fire Hazard Indices

Ignitability	14
Spread-of-flame	7
Smoke-developed	2

Workability

Machining	Machines well.
Fixing	No difficulty has been experienced with the use of standard fittings and fastenings.
Gluing	As with most high-density species, machining and surface preparation should be done immediately before gluing.
Finishing	Will readily accept paint, stain and polish. High tannin and extractives content can result in staining of painted surfaces exposed to the weather.

Environmental Description

Insulation value (U)	0.22
Certification	Generally available

Fire Hazard Properties: Wall and Ceiling Lining (AS/NZS 3837)

Material Group	3
Average extinction area	Less than 250m²/kg
Bushfire flammability	Listed as a bushfire-resisting timber in AS 3959

Name	Hoop pine
Species Name	*Araucaria cunninghamii*
General Availability	Readily
Source	Hoop pine is a large tree occurring in drier rainforests from Hastings River to far north Queensland and in some places as far inland as 300 km. It is also grown in plantations, predominantly in south Queensland. While available from native forests, it is mainly a plantation timber.
General Performance	Hoop pine has traditionally been a joinery timber used for doors, window sashes and other internal and external joinery. Hoop pine is good for inside use in dry conditions. It varies in acceptance of preservative impregnation. May be attacked by the hoop pine borer in tropical areas. Can be used externally above ground if treated. Do not use in-ground.

Appearance

Description	The heartwood ranges from pale cream to light yellow-brown with little difference between heartwood and sapwood. The grain is very fine and even textured. Growth rings usually visible but indistinct.

Durability

Durability Class	Outside above ground: Class 4, In-ground contact: Class 4
Lyctis Susceptability	Not susceptible
Termite Resistance	Not resistant
Preservation	Sapwood readily accepts impregnation but the heartwood cannot be adequately treated.

Stability - Unit Shrinkage

Radial	0.18% (per 1% MC change)
Tangential	0.23% (per 1% MC change)

Physical Properties - Seasoned

Density (kg/m^3)	550
Strength Group	SD5
Joint Group	JD4
Hardness (kN Janka)	3.4 (native forest material)

Early Fire Hazard Indices

Ignitability	14
Spread-of-flame	7
Smoke-developed	2

Workability

Machining	Machines and turns well to a smooth surface.
Fixing	No difficulty has been experienced with the use of standard fittings and fastenings.
Gluing	Can be satisfactorily bonded using standard procedures.
Finishing	Will readily accept stain, polish and paint.

Environmental Description

Insulation value (U)	0.14
Certification	Generally available
Bushfire flammability	Listed as a bushfire-resisting timber in AS 3959

Name	Jarrah
Species Name	*Eucalyptus marginata*
General Availability	Limited
Source	Jarrah is a dominant species in forests in south-west of Western Australia.

Appearance

Description	The heartwood is dark red. Sapwood is usually pale yellow. The grain is generally straight, moderately coarse textured and even.

Durability

Durability Class	Outside above ground: Class 2, In-ground contact Class 2.
Lyctis Susceptability	Susceptible
Termite Resistance	Resistant
Preservation	Sapwood readily accepts impregnation but the heartwood cannot be adequately treated.

Stability - Unit Shrinkage

Radial	0.24% (per 1% MC change)
Tangential	0.30% (per 1% MC change)

Physical Properties - Seasoned

Density (kg/m³)	835
Strength Group	SD4
Joint Group	JD2
Hardness (kN Janka)	8.5

Early Fire Hazard Indices

Ignitability	13
Spread-of-flame	6
Smoke-developed	3

Workability

Machining	Machines and turns well.
Fixing	Satisfactory with standard fittings and fastenings. Some care is needed when nailing.
Gluing	Can be satisfactorily bonded using standard procedures.
Finishing	Will readily accept paint, stain and polish.

Environmental Description

Insulation value (U)	0.20
Certification	Generally available

Fire Hazard Properties: Wall and Ceiling Lining (AS/NZS 3837)

Material Group	3
Average extinction area	Less than 250m²/kg
Bushfire flammability	Included in Table E1 of AS 3959

Name	Messmate
Species Name	*Eucalyptus obliqua*
Other Name	Australian Oak
General Availability	Limited
Source	Large hardwoods found throughout wetter areas of Tasmania, Victoria, and southern NSW. E. obliqua has a wide distribution, occurring in wet forests but also extending into drier areas.
General Performance	While external surfaces need to be painted, Messmate have performed well in timber windows and door for over a century. The timber works and finishes very well, and is readily available with environmental certification.

Appearance

Description	Colour varies from cream to pale to reddish-brown. The timber has straight, open and even grain with a texture that is open, uniform and fairly coarse.

Durability

Durability Class	Outside above ground Class 3, In-ground contact; generally Class 3.
Lyctis Susceptability	Susceptible
Termite Resistance	Not resistant
Preservation	While the sapwood can be treated, the heartwood is resistant.

Stability - Unit Shrinkage

Radial	0.23% (per 1% MC change)
Tangential	0.36% (per 1% MC change)

Physical Properties - Seasoned

Density (kg/m^3)	780
Strength Group	SD3
Joint Group	JD3
Hardness (kN Janka)	7.1

Early Fire Hazard Indices

Ignitability	14
Spread-of-flame	8
Smoke-developed	3

Workability

Machining	Moulded surfaces are true and clean, with even end grain. Holds edges well.
Fixing	Fixes well.
Gluing	Glues satisfactorily with most common adhesives.
Finishing	Readily worked to a smooth, lustrous surface. Most finishes adhere very well. Stains very well.

Environmental Description

Insulation value (U)	0.17
Certification	Generally available

Fire Hazard Properties: Wall and Ceiling Lining (AS/NZS 3837)

Material Group	3
Average extinction area	Less than 250m^2/kg
Bushfire flammability	Included in Table E1 of AS 3959

Name	Spotted gum
Species Name	*Corymbia citriodora* subsp. variegata, *C. citriodora* subsp. citriodora, *C. maculata*
General Availability	Readily
Source	*Corymbia citriodora* occurs mainly in the coastal areas of northern New South Wales and southern Queensland through to North Queensland. *C. maculata* occurs from Bega to the mid-north NSW coast.

Appearance

Description	Heartwood is pale to dark brown. The sapwood is distinctly paler. The texture is moderately coarse and grain variable.

Durability

Durability Class	Outside above ground: Class 1, In-ground contact: Class 2
Lyctis Susceptability	Susceptible
Termite Resistance	Resistant
Preservation	The sapwood can be treated but the heartwood is resistant.

Stability - Unit Shrinkage

Radial	0.3% (per 1% MC change)
Tangential	0.4% (per 1% MC change)

Physical Properties - Seasoned

Density (kg/m³)	~950 - 1000
Strength Group	SD2
Joint Group	JD1
Hardness (kN Janka)	10.1

Early Fire Hazard Indices

Ignitability	13
Spread-of-flame	3
Smoke-developed	3

Workability

Machining	Machines well due to its natural greasiness.
Fixing	Easy to work. Straight-grained material can be bent well. Unseasoned wood can be corrosive to nails and aluminium.
Gluing	Gluing can be difficult where phenolic type adhesives are used.
Finishing	Will readily accept paint, stain and polish. Has lower tannin content than most other eucalypts, therefore staining of paintwork, brickwork etc, as a result of water running over unpainted timber surfaces, is less likely to occur.

Environmental Description

Insulation value (U)	0.23
Certification	Generally available

Fire Hazard Properties: Wall and Ceiling Lining (AS/NZS 3837)

Material Group	3
Average extinction area	Less than 250m²/kg
Bushfire flammability	Listed as a bushfire-resisting timber in AS 3959

Name:	Kwila / Merbau
Species Name:	*Intsia bijuga, I. Palembanica*
Other Names:	Johnstone River teak, scrub mahogany (north Queensland), merbau (Malaysia), vesi (Fiji), ipil (Philippines), melila, bendora (Papua New Guinea).
General Availability:	Readily
Source	A large tropical hardwood found from Southeast Asia to Papua New Guinea, the Philippines, Solomon Islands, Fiji and occasionally north Queensland.
General Performance	A highly durable hardwood regularly used as sills in window frames. In windows, all sides should be sealed to prevent staining of surrounding work.

Appearance

Description	Heartwood yellowish-brown or orange-brown when first cut, turning darker with age to brown or deep reddish brown. Sapwood white, pale yellow or buff and sharply differentiated from heartwood. The grain is variable but usually interlocked or wavy, texture is coarse but even. Rather greasy to the touch.

Durability

Durability Class	Outside above ground: Class 1, In-ground contact: Class 3
Lyctis Susceptability	Susceptible
Termite Resistance	Resistant.
Preservation	Sapwood only accepts preservative impregnation.

Stability - Unit Shrinkage

Radial	0.19% (per 1% MC change)
Tangential	0.30% (per 1% MC change)

Physical Properties - Seasoned

Density (kg/m³)	830
Strength Group	SD3
Joint Group	JD2
Hardness (kN Janka)	8.6

Early Fire Hazard Indices

Spread-of-flame	0
Smoke-developed	5

Workability

Machining	Working properties variable. Cuts cleanly but may have a blunting or gumming effect on cutting edges. Cutting angle should be reduced to 20° when planing quarter-sawn stock. Turns well.
Fixing	Kwila tends to split unless pre-bored, but holds fastenings well. and fastenings.
Gluing	Glues satisfactorily except with casein glues.
Finishing	It takes paint, stain and polish well, but gum bleed-through or oily patches may affect the finish.

Environmental Description

Insulation value (U)	0.2
Certification	Occasionally available.

Fire Hazard Properties: Wall and Ceiling Lining (AS/NZS 3837)

Material Group	3
Average extinction area	Less than 250m²/kg.
Bushfire flammability	Listed as a bushfire-resisting timber in AS 3959.

Western red cedar, *Thuja plicata* — Imported

Name	Western red cedar
Species Name	*Thuja plicata*
Other Names	Western cedar, red cedar
General Availability	Readily
Source	A large softwood of wet forests on the North American west coast from Oregon and Montana to British Columbia.

Appearance

Description	Heartwood varies from pale brown to dark brown. Sapwood is yellowish white. The grain is fine textured and straight grained with distinct growth rings.

Durability

Durability Class	Outside above ground: Class 2, In-ground contact: Class 3.
Lyctis Susceptability	Not susceptible
Termite Resistance	Resistant
Preservation	Sapwood is rarely present in sufficient quantities to warrant preservation. Penetration of heartwood by preservatives is negligible.

Stability - Unit Shrinkage

Radial	(~ 1.5% from green to dry)
Tangential	(~ 3% from green to dry)

Physical Properties - Seasoned

Density (kg/m^3)	380
Strength Group	SD8
Joint Group	JD5
Hardness (kN Janka)	1.5

Early Fire Hazard Indices

Ignitability	15
Spread-of-flame	10
Smoke-developed	3

Workability

Machining	Machines and turns well to a smooth surface.
Fixing	Ferrous fastenings and fittings may be corroded by wood extractives when used in weather-exposed situations.
Gluing	Can be satisfactorily bonded using standard procedures.
Finishing	Readily accepts paint, stain and polish.

Environmental Description

Insulation value (U)	0.11
Certification	Generally available.
Bushfire flammability	Not included in the tables of AS 3959

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Introduction

Timber is a renewable material that is both beautiful and durable. It is specified for a broad range of design applications throughout Australia and overseas. Light and versatile, it is used in interior and exterior applications including framing, roofing, lining, cladding, flooring, fit out and joinery for all building types. It can be used in its original shape, rough sawn or hewn to size, dressed to a smooth finish, machined into a variety of shapes or sliced into sheets of veneer. Timber can be machined to realise patterns, filigrees and geometrically complex forms.

Different species possess different basic properties and, therefore, provide a natural variety of aesthetic and structural options. Wood can be transformed into manufactured, reassembled products, including glue-laminated timber, particleboard, plywood and laminated veneer lumber. Each engineered product has its own structural and aesthetic properties and qualities in building.

Timber is easy to work and handle, is a store for carbon and has a low embodied energy.

Pump house, Longford, Tasmania, 1841.

Queenscliff Residence by John Wardell Photographer - Trevor Mein

Timber is easy to work and handle, is a store for carbon and has a low embodied energy. While the trees are growing, they are home to a variety of flora and fauna. Biodiversity is maintained through the forestry cycle as the trees are regrown. The manufacturing process for timber produces fewer pollutants for the air and water than many of its alternatives. Timber is also reusable, recyclable and biodegradable.

A comprehensive understanding of the natural growth characteristics and material behaviour of timber is essential in successfully designing, specifying and constructing with timber. This document aims to present an overview of timber as a material and provide detail for timber in interior applications.

The guide combines information about species, material capability and assembly with an interior design approach to colour, pattern and performance with the full range of wood products.

Denton Crocker Marshall's Melbourne Museum.

1

Visual Palette

Timber is a natural, grown material and as such is susceptible to variation. This variation, when well detailed and considered, adds a richness and texture to surfaces, joinery and furniture. The key visual characteristics of timber are described in detail below.

1.1 Colour

Colour, colour consistency, and its combination with grain pattern are critical aspects of visual appeal. However, Australian Standards do not contain any requirements for colour or colour consistency. In the Australian Standards, colour is held to be a variable characteristic of the species. Industry standards and designer specifications regularly place restrictions on the variability of colour. Usually, boards that are significantly outside a mean average colour range are excluded as being too light or too dark. Occasionally, boards are sorted into colour groups between agreed boundary colours.

Particular species are associated with particular colours, even though only a proportion of the timber from the species may match this expectation. An example of this is Tasmanian Myrtle, *Nothofaguscunninghamii*. In the market, myrtle is perceived as a red to red-orange timber, yet in the forest the colour of myrtle wood varies from nearly white, through pink to red. Only the red timber is regularly milled. Species information sheets are available through the WoodSolutions website which include an indication of possible colour range within a species. Designers must ensure that if a colour range is to be specified, it is clearly agreed within the supply chain.

An analysis of available colours suggests that while wood is generally brownish, most timber can be sorted into one of five main groups of brown shown in Figure 7: yellow, pinks, browns, red-oranges, blacks. Each of those groups can then be graduated from light to dark or pale to intense.

While individual species may produce timber of one major colour group, it is quite common for timber of a particular species to fall in two or three groups. Blackwood is an example, falling into groupings of both browns and blacks.

Yellows Huon Pine, Radiata

Grey-Blacks Walnut, Blackwood

Pinks Tas Oak, Vic Ash

Browns Blackwood, Blackbutt

Red-Oranges Myrtle, Cedar xxxx distorted

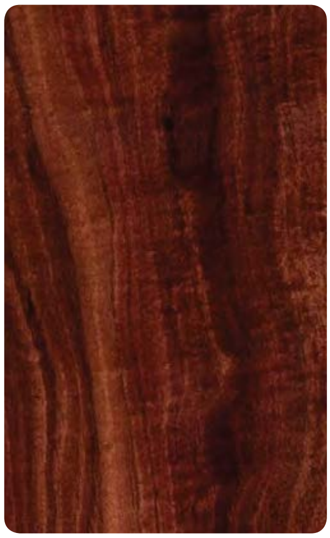
Figure 7: Common colour groups in timber.

1.1.1 Colour Variegation

Almost all timber has some variegation in the colour of the wood, generally as the result of growth rings. Other variation of colour can also occur due to the age of various parts of the wood and changing growing conditions. The level of variegation acceptable in a piece depends on the application and the base colour. Variegation is much more noticeable in pale colour timber. Examples are shown in Figure 8.

Silver Wattle

Radiata Pine



Blackwood

Figure 8: Colour variegation within timber.

1.1.2 Colour Matching

Timber is generally too variable to match pieces to a particular colour. The best case achievable is matching the timber within agreed colour boundaries. The closer together the boundaries of a particular group, the more consistent the colour match will be. It also means that there will be less timber from any group of boards or veneer accepted into a particular group. Even when matched, the timber still needs to be blended during assembly or installation to ensure that there is a good mix of colour and tone throughout the project area.

1.1.3 'Colourfast' Considerations

Like many materials, no wood, wood finish or stain is completely 'colourfast' if that is defined as 'no change of colour over time'. Raw wood, without a stain or finish, will change colour in reaction to ambient conditions. The addition of stains and/or topcoats will slow the rate at which the transformation will occur, but not stop it.

John Wardle Architects: Flinders House.

1.2 Grain, Texture and Figure

1.2.1 Grain

Visually, grain is the direction, size, appearance, or quality of the fibres in timber. The most common grain variation is the pattern of the growth rings on the surface manifested from cutting timber at varying angles to the tree growth.

Grain pattern

Hardwood

Softwood

Board sawing grain

Quartersawn
Timber sawn with the average inclination of the growth rings to the wide face is not less than 45°.

Backsawn
Timber sawn so that the growth rings are inclined at less than 45° to the wide face.

1.2.2 Texture

Texture is specifically a description of the size and quality of the wood elements of grain. Texture can be coarse, fine, even or uneven. Softwoods are normally considered to be fine textured, whereas hardwoods may span the range from coarse to fine. Mountain ash, ***Eucalyptus regnans***, is an example of a coarse textured hardwood, but Brushbox, ***Lophostemanconfertus*** – also a hardwood – is considered to have a fine texture.

Fine → ***Coarse***

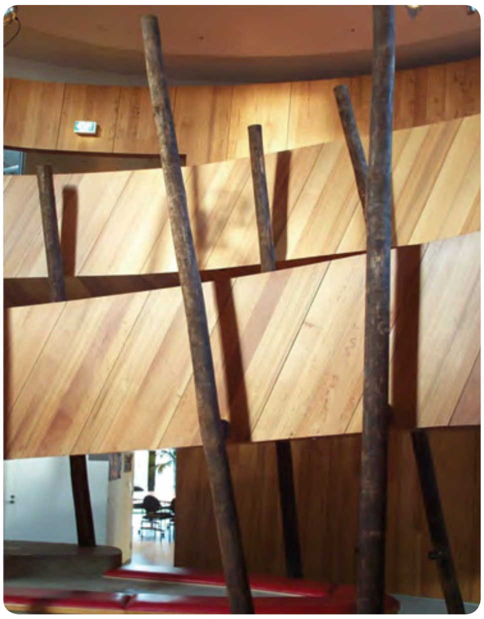
Softwood

Hardwood

Surface texture of the timber varies with sawing and machining. Timber rough sawn by circular blade may have arc-shaped ridges across its surface, or have a rough fibrous surface. Bandsawn timber can often have vertical ridges across the surface. Split timber surface will have an uneven surface which follows grain fibres. Planed or ‘dressed’ timber will have a smooth surface, with texture only present from grain fibres. Structural framing timber is often machined with a series of longitudinal ribs.

Rough sawn (circular saw).

Planed.



Denton Cocker Marshall’s Melbourne Museum.

1.2.3 Figure

Figure is the pattern produced on the cut surface of wood by annual growth rings, rays, knots, deviations from regular grain such as interlocked and wavy grain, and irregular colouration.

Figure is natural visual characteristics in the timber caused by:

- growth patterns
- fire or mechanical damage
- insect marks
- stain and bacterial infection.

Knots
are a portion of a branch or limb that has been surrounded by subsequent growth of the stem. The shape of the knot as it appears on a cut surface depends on the angle of the cut in relation to the long axis of the knot.

Burl or burr:
This is a large abnormal growth or protuberance on either the trunk or branches, and is formed by local development of numerous dormant buds, often caused by injury to the tree. The interwoven mass of wood elements gives an attractive and unusual figure whichever way it is cut.

Wavy grain and fiddle-back:
When quarterly sliced, logs with wavy grains produce beautiful veneer with wavy patterns. Light is reflected at varying angles from the surfaces because the individual elements are cut across at varying angles. Figures with large undulations are described as 'wavy', while those with small, regular undulations are 'fiddleback'.

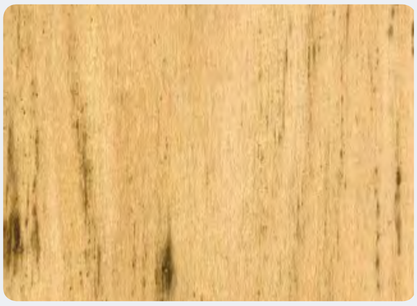
Commonly found in such species as Red Gum (*Eucalyptus camaldulensis*), Blackwood, Mountain Ash, Alpine Ash, Jarrah (*E. marginata*) and others.

Bird's eye:
This figure can be seen on back-cut surfaces of certain species as numerous rounded areas resembling small eyes. It is caused by small conical depressions of the fibres.

Pommele:
This figure resembles a puddle surface during a light rain: a dense pattern of small rings enveloping one another. Some say this has a 'suede' or 'furry' look.

Gum vein:
A ribbon of gum between growth rings, which may be bridged radially by wood tissue at intervals. Gum is also known as kino.

Black speck:
Black speck is a fungal stain in the timber caused by the attack of certain insects leaving pinholes in the wood.



Gum cluster:
Clusters of small or short gum veins between growth rings, corresponding to damage or other event.

Black heart:
Various fungi and bacteria can stain or colour the timber either in the standing tree, or as it is milled and dried. Some stains are desirable, such as the 'blackheart' feature found in Sassafras, while others, such as the blue stain found in slow-drying hardwood, are not.

Hobnail:
The pattern of pinholes or streak marks that occur along a growth ring in quartersawn timber caused by some insect attack.

Lyctid borer:
Sometimes known as the powder post borer, this is the larval stage of lyctid beetle. The borer consumes the starch-rich sapwood of some hardwoods, leaving behind a sawdust-filled honeycomb of wood.

Australian Standards limit the use of lyctid susceptible sapwood throughout Australia.

Surface check:
A separation of fibres along the grain forming a fissure, but not extending through the piece from face to face. Checks commonly resulting from stresses built up during seasoning. Surface checks affect the integrity of veneers and provide a trap for moisture in solid timber sections.

Pin hole:
Small, regularly sized but irregularly spaced holes on the surface of the wood caused by insect attack in the tree or the timber. They are often accompanied by discoloration around the hole.

1.3 Combinations and Patterns

Adjacent slices or leaves of veneer typically have similar patterning because the changes in grain and features/figuring vary gradually through the timber. Similar veneers can be placed in varying arrangements with striking effects. Similar patterns can also be achieved with high appearance grade solid timber. This process is termed ‘matching’.

When two sheets of veneer are matched, the ‘tight’ and ‘loose’ faces may alternate in adjacent leaves. They reflect light and accept stain differently, and this may result in a noticeable colour variation in some species.

It is essential that the veneers are balanced on either face when laid on a panel; an unbalanced panel would warp as it gains moisture unevenly. Veneers are laid with grain perpendicular to the grain of the board. Generally, the same species and thickness of veneer should be applied to both sides of the board. If differing species are required on the face and back, it is essential that both veneers have similar strength properties and dimensional behaviour characteristics. The grain of the veneer should be generally parallel to the long edges of the panel.

It is common for veneered engineered boards to have veneers of varying width between boards. i.e. three, four or five strips of veneer per 1,200 mm wide board. Procuring a number of boards with the species of veneer with the same matching pattern from an individual supplier may not result in a set of boards that can be matched end-to-end. In such cases, a random match pattern can be adopted or the procurement should be managed carefully.

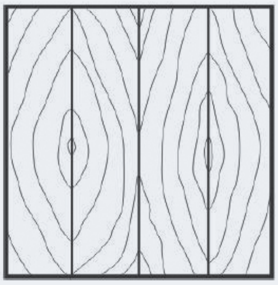
It is essential that the veneers are balanced on either face when laid on a panel; an unbalanced panel would warp as it gains moisture unevenly.

Bates Smart: Sydney Water.

Patterns

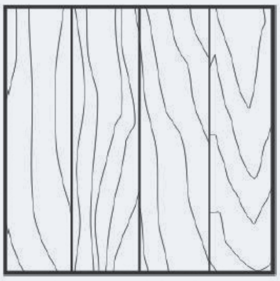
Book matching

Book matching is based on the principle of creating a mirror image. Successive veneer leaves in a flitch are turned over like the pages in a book, and edge-joined in this manner. Since the reverse side of one leaf is the mirror image of the succeeding leaf, the result is a series of pairs. Book matching may be used with plain, quarter or crown sliced veneers.



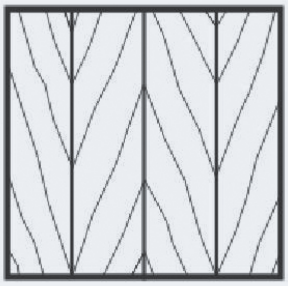
Random matching

Individual leaves are randomly matched together with the intention of dispersing characteristics such as knots or gum veins more evenly across the sheet. In this way, veneers from several logs may be used in the manufacture of a set of panels.



Herringbone matching

Veneer strips are used and matched to both sides of a centre line, at an angle to it. This can produce a downward or upward 'V'.

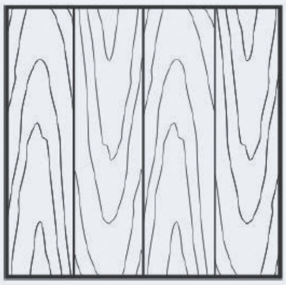


Slip matching

Successive veneer leaves in a flitch are 'slipped' one alongside the other and edge-glued in this manner. The result is a series of grain repeats, but no pairs. This method gives the veneer uniformity of colour because all faces have the same light refraction.

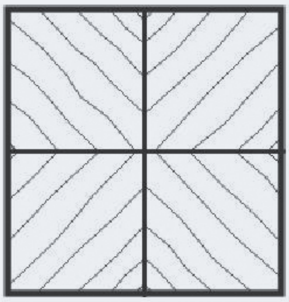
Reverse slip matching

This method is generally used with crown cut veneers. Veneer leaves are slip matched, then every second leaf is turned end-to-end. The method is used to balance crowns in the leaves so that not all the crowns appear at one end.



Diamond and reverse diamond matching

Sheets are cut on an angle and quarter-matched to produce a diamond figure. Reverse diamond matching uses the same principle with the same kind of veneers, but the grains are matched to produce an 'X' pattern rather than a closed diamond.



Other combinations

The above methods are frequently used for matching veneers. However, other individually designed matching methods can be used to develop beautiful unique patterns by utilising different patterns and colours of veneers.

Inlay

Cabinetmakers often frame a highly decorative wood grain with a plainer grain to accent it. To delineate it, a narrow strip or dark or patterned veneer is cut in along the joint line. This technique is called inlay. It has also come to mean cutting patterns into the basic veneer.

Marquetry

Veneer faces of various kinds are made up with small segments of veneer cut into patterns and fitted together. Often many different species and grain patterns, including many of the most exotic grains, are used in marquetry work. Beautiful effects can be obtained using the marquetry technique. It is generally applied in furniture manufacture and can be quite ornate.

2

Connecting Timber Elements - Joint Types, Fixing and Connections

The following section discusses options available to the designer for connecting stick and panel type elements.

2.1 Joint Types

Timber is relatively easy to shape and work into connecting joints, such as dovetails, with readily available equipment. Timber can be prefabricated by machine or hand, or can be worked on-site to suit particular scenarios. Connections between timber elements, whether stick type framing or panels, can be achieved with carpentry joints, metal fasteners or glue, or as a combination.

2.1.1 Carpentry Connections

Carpentry type connections involve the machining of the intersecting elements to create a joint such as housing, halving or dovetailing. Such connections are typically used in visually expressed applications or applications where locating elements relative to each other is required, ensuring good fit, before using a mechanical fastener for the connection.

David Travalia: Hollybank Training Centre.

Chris Connell Design: Brimar Court.

Careful specification of fasteners and design of the fastener array is essential in order to maintain control over the appearance of the finished article.

2.1.2 Metallic Fasteners

Metallic fasteners such as nails, screws and bolts, or specialist proprietary products such as hangers and cleats, are used to secure elements. Fasteners can be machine or manually fixed. Size, form, number and spacing of fasteners required in structural applications is defined in *AS 1720.1 – 1997 Timber Structures: Design Methods* or *AS 1684.2/3/4 – 2010 Residential Timber Framed Construction* but for smaller scale applications the fasteners are specified by the designer or builder. Fasteners may require pre-drilling to prevent splitting of timber on fixing. Fasteners of certain materials, such as ferrous metals, may react with extractives in some timber species resulting in accelerated corrosion of the fastener and staining of the timber in damp environments.

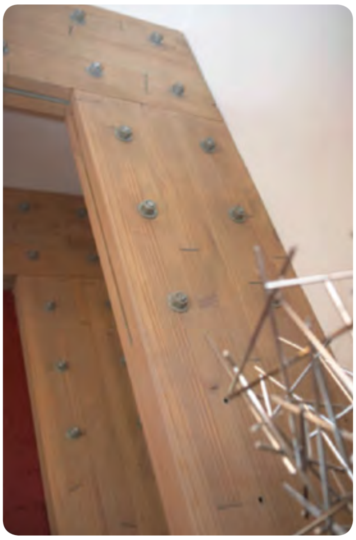
The visual characteristics of different fasteners vary significantly. Careful specification of fasteners and design of the fastener array is essential in order to maintain control over the appearance of the finished article.

Counter-sunk screws: cross, square and hex drive.

Raised hex-head: roofing, machine, bolt.

Nails: machine & hand driven.

Figure 6: Screw, bolt and nail head types



Justin Mallia: East St Kilda house extension.

Johnson Pilton Walker: National Portrait Gallery.

Jorge Hrdina: Lilypad House.

2.1.3 Adhesives

Gluing is often used as a connection in conjunction with metallic fasteners, such as screws, which provide a temporary clamping force for the glue to cure, and provide redundancy in the event of glue failure. Glues or 'adhesives' can either be factory or site applied. Factory-applied adhesives can typically offer a higher performance because of the availability of skilled labour and controlled environmental conditions.

Adhesives are used in internal applications to make wood products such as glue-laminated members, or to create joinery and carpentry elements. Timber glue-laminated for general structural applications is manufactured to the requirements of *AS 1328 - 1998: Glued-laminated structural timber*. Commercially produced glue-laminated timber made to this standard generally feature Type A waterproof phenolic bonds with a distinct dark brown glue-line.

Timber laminated in the joinery for non-load-bearing elements does not need to meet the requirements in ***AS 1328 - 1998: Glued-laminated structural timber.*** It can be glued with adhesives that comply with, or are at least equivalent in performance with adhesives complying with, ***AS 2754.2 Adhesives for timber and timber products – Polymer emulsion adhesives*** and achieving at least a Type B bond to ***AS/NZS 2098.2:2006: Methods of test for veneer and plywood – Bond quality of plywood (chisel test).*** Joints made with adhesives that do not give this performance should be held together by other means in the event that the glue fails.

Two glues commonly used in joinery are polyurethanes and PVA emulsions. Polyurethanes glues are thermosetting glues that react with the moisture in the wood to produce a clear polyurethane resin. They have good strength and some gap-filling capabilities, though their performance is improving with further research.

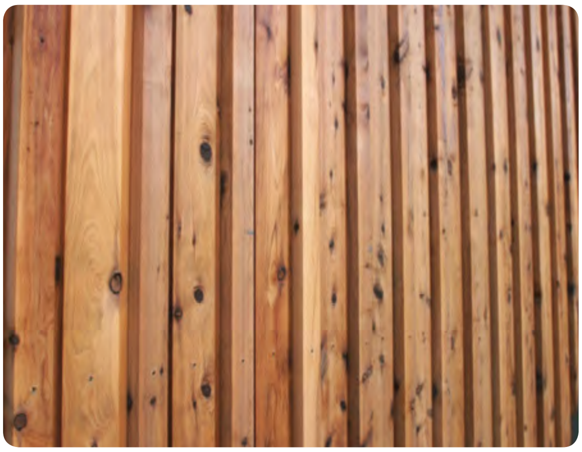
Poly Vinyl Acetate (PVA) is a thermoplastic glue made by polymerising vinyl acetate alone or with other polymers. Most cure at room temperature and set rapidly. They are easy to use, result in a clear glue-line and have good gap-filling properties, though steady pressure on the joint is required. Cross-linked glues have better moisture resistance than other types.

Timber craftsmen and builders or glue manufacturers are typically the best source of information for the specification of glues.

2.1.4 Joint Arrangements

Seven basic timber-to-timber framing connections can be seen below. These connection types are used in various scales from furniture and joinery to structural frames. Connection performance should consider the key points listed below:

- Buildability: The connection should be designed such that it is relatively simple to implement in the relevant scenario whether on-site in an awkward position or in a factory. A well-designed jointing detail provides scope to on-site tolerance in the fixing of the elements.
- Visual characteristics: In cases where the junction between timber elements is visually expressed, the type and form of the connection and fixing will be key. For example, a housed joint allows the grain of the one intersecting element to be visually continuous past the connection. Other types of hidden connections can be achieved with mechanical fasteners or dowels.
- Moisture movement: As described in Section 3.1.4, timber moves differentially between the radial, tangential and longitudinal directions with changing moisture content. Such differential movements can lead to problems with visual and structural fit of joined members. For example, in the case of a housed joint the housed member will shrink across the grain under lower moisture content more than the housing member along the grain leading to a gap opening. This gap may then make the joint flexible and unfit for purpose structurally, expose the connection to moisture ingress or be visually unacceptable. Connections should be detailed carefully considering potential for such movement.



Billard Leece Partnership Pty Ltd: Kardinia Health Super Clinic

Daryl Jackson Sinclair Knight Mertz Lyons: Victorian County Court

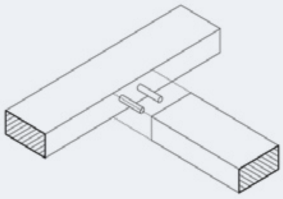
Joint	Description	Joint	Description

Mortice and tenon

Visually expressed furniture, cabinetry, doors and windows. Can be a short tenon in a blind hole. May be pegged, wedged, or interference fit.

Ease of Construction ★☆☆

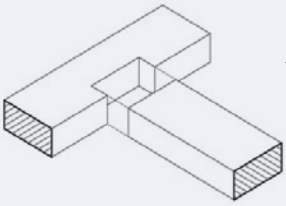
Dowel



Furniture, joinery, windows and doors to make concealed connections. Joint typically glued.

Ease of Construction ★☆☆

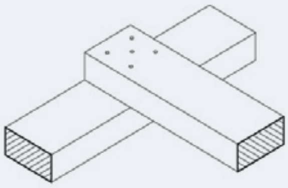
Housed



General joinery. Can be fastened with nails or screws and/or glued.

Ease of Construction ★★☆

Screws/nails in overlap



Internal framing and carcassing. Many options for screws and nails.

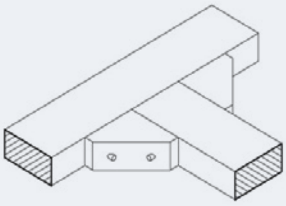
Ease of Construction ★★★

Half housed

General joinery. Can be fastened with nails or screws and/or glued.

Ease of Construction ★★☆

Fixing blocks



Internal framing and carcassing.. Many options for screws and nails.

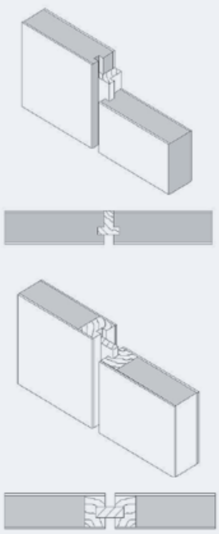
Ease of Construction ★★★

Biscuit

Biscuit cutter and glue required. Furniture, joinery, windows & doors. Concealed connections.

Ease of Construction ★★☆

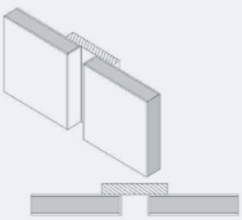
Loose tongue



Loose tongue of varying form between two rebated panels. Tongue size, gap size and material can vary.

Ease of Construction ★☆☆

Backing strip

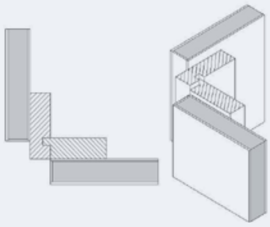


Visually expressed furniture, cabinetry, doors and windows. Can be a short tenon in a blind hole. May be pegged, wedged, or interference fit.

Ease of Construction ★☆☆

Joint	Description	Joint	Description

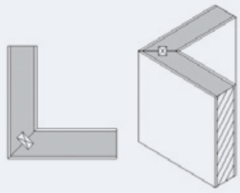
Backing strip corner



Backing strip of contrasting of similar timber used to join panels. Backing strip may be jointed panels of larger block continuous along join.

Ease of Construction ★★☆

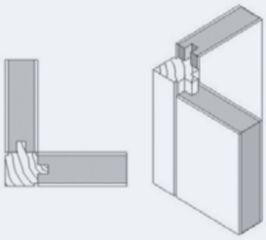
Mitre loose tongue corner



Mitre joint to preserve continuation of face veneer of adjoining elements. Loose tongue used to join elements.

Ease of Construction ★☆☆

Loose T&G corner



Solid timber tongued element usually matching face veneers of adjoining elements.

Ease of Construction ★☆☆

Tongue & groove mitred corner

Mitre joint to preserve continuation of face veneer of adjoining elements.

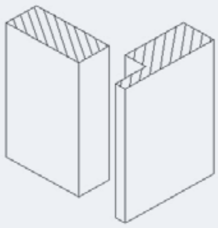
Ease of Construction ★☆☆

Longitudinal Notch

One or both intersecting pieces profiled to create a male and female junction.

Ease of Construction ★★☆

Longitudinal Lap



One or both intersecting pieces profiled to create a male and female junction.

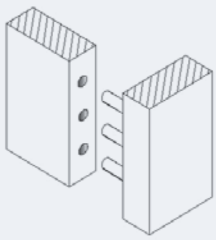
Ease of Construction ★★☆

Dovetail

Traditional connection in cabinetry, though less common in joinery. Complex to make by hand and difficult to machine.

Ease of Construction ☆☆☆

Dowel



Common in modern furniture, especially self-assembly items. Concealed and relatively simple to fabricate.

Ease of Construction ★★☆

3

Coatings and Finishes

Coating timber used in interior applications allows the timber to be cleaned and wiped free of potentially staining substances, thus improving its service life.

The following section presents a summary of different types of coatings and finishes relevant to the interior use of timber. The field of coatings and finishes is a rapidly evolving sector with advancing technology, and growing concerns over public health and ecological issues leading to a significant increase in the use of water-based products. As such, more detailed information on products and product types for the development of project specifications should be sourced through coating manufacturers and suppliers and through reference to *AS/NZS 2311 Guide to the Painting of Buildings*.

McBride Charles Ryan: Letterbox House

3.1 General

Coating timber with a well-maintained paint or a high-build translucent finish can increase the service life of the element by improving resistance to wear and abrasion, reduce colour change in the timber associated with exposure to UV, enhance the colour, grain and feature of the timber, and reduce decay in exposed elements. Coatings shed water off the surface of the timber and slow the uptake of moisture, particularly for the relatively porous end-grain of the timber. Providing a coating to timber used in interior applications allows the timber to be cleaned and wiped free of potentially staining substances, thus improving its service life.

Good-quality paint systems provide a water-resistant and generally long-lasting finish. Stains and water repellents do not last as long and require more frequent reapplication than paints. Factory-coated finishes tend to have significantly longer service lives than site-applied finishes, as factory finishing allows superior coatings to be applied in controlled conditions. The coating on factory-finished elements is highly durable and should not require refinishing for many years. The coating should be protected during storage, installation and subsequent construction. Factory-finished coatings often require special repair. Non-compatible coating will often not adhere to the surface properly. If the finish is damaged, consult the supplier.

Finished timber can often be seen to ‘yellow’ over time as a result of using amber binders or vehicles for the stains and/or topcoats. To avoid yellowing, specify ‘non-yellowing’ finishing materials. The addition of an ultraviolet (UV) inhibitor will slow, but not prevent, the gradual colour change of the wood, the stain and the finish system.

The expected life of paint or other finishes depends on the quality and type of coating, the care taken in application and the condition of the underlying timber. Timber characteristics which effect the performance of the applied finish includes:

- **Species** – The performance of different finishes varies with the species and density of the timber onto which the finish is applied. Finish manufacturers should be consulted for detailed information on the varying performance with changing species.
- **Surface texture** – Smooth surfaces offer better substrates for painting than rough surfaces, therefore dressed timber offers a better performance than sawn timber for conventional paint systems. Rough sawn timber can be used with oils and stains.
- **Moisture content** – Seasoned timber (10 to 15% MC) provides a more stable substrate than green timber, thus reducing problems of cracking associated with movement under a coating. Moisture egress associated with drying in-situ of green timber can lead to blistering of finishes with low vapour permeability such as paint, so stains and oils are best adopted if the timber is green or with a high MC.
- **Section profile** – Section edges should be arrissed or rounded to prevent concentration in coating stress for paint finishes. For surface coating systems such as paint, sections adopted should be as dimensionally stable as possible such as quartersawn rather than backsawn.
- **Material features** – Heartwood has a higher natural durability than sapwood but is harder to treat with impregnated treatments. Timber features or 'defects' will affect the finish performance. Gum pockets can lead to resin exudation and staining unless pre-treated and sealed. Aromatic oils can lead to drying retardation and staining if surface oils are not removed. Knots can cause premature cracking, staining and resin exudation can occur unless treated with knotting varnish or manufacturers recommend treatment. Bark can lead to premature failure of all film-forming finishes if not removed. Extractives may cause topcoat discolouration or blistering unless surface extractives are removed with a solvent wash prior to priming.

Barwon Heads by Inarc Architecture. Photographer – Peter Clarke

H2o Architects: Deakin University International Centre & Business Buildings.

Finishes

Finishes	Transparency	Typical use	Approx VOX	Colour range / appearance
Untreated, 'bare'	High transparency	Linings Furniture Joinery Carcassing	None	Colour by species & level of weathering
Oil		Linings Furniture Joinery	<455g/L	Looks like wet timber
Clear varnish		Linings Furniture Floors Joinery	<15g/L	Matt, satin or gloss finish. Grain visible.
Pigmented varnish		Linings Furniture Floors Joinery	<155g/L	Matt, satin or gloss finish. Toned grain visible. Colour range by manuf.
Stain		Linings Furniture Floors Joinery	<10g/L	Coloured grain visible. Matt, satin or gloss finish. Colour range by manuf.
Paint	Opaque	Linings Furniture Floors Joinery Carcassing	<5g/L	Opaque smooth surface. Vast colour range available.

Campbell Drake: Dusk Bar.

4

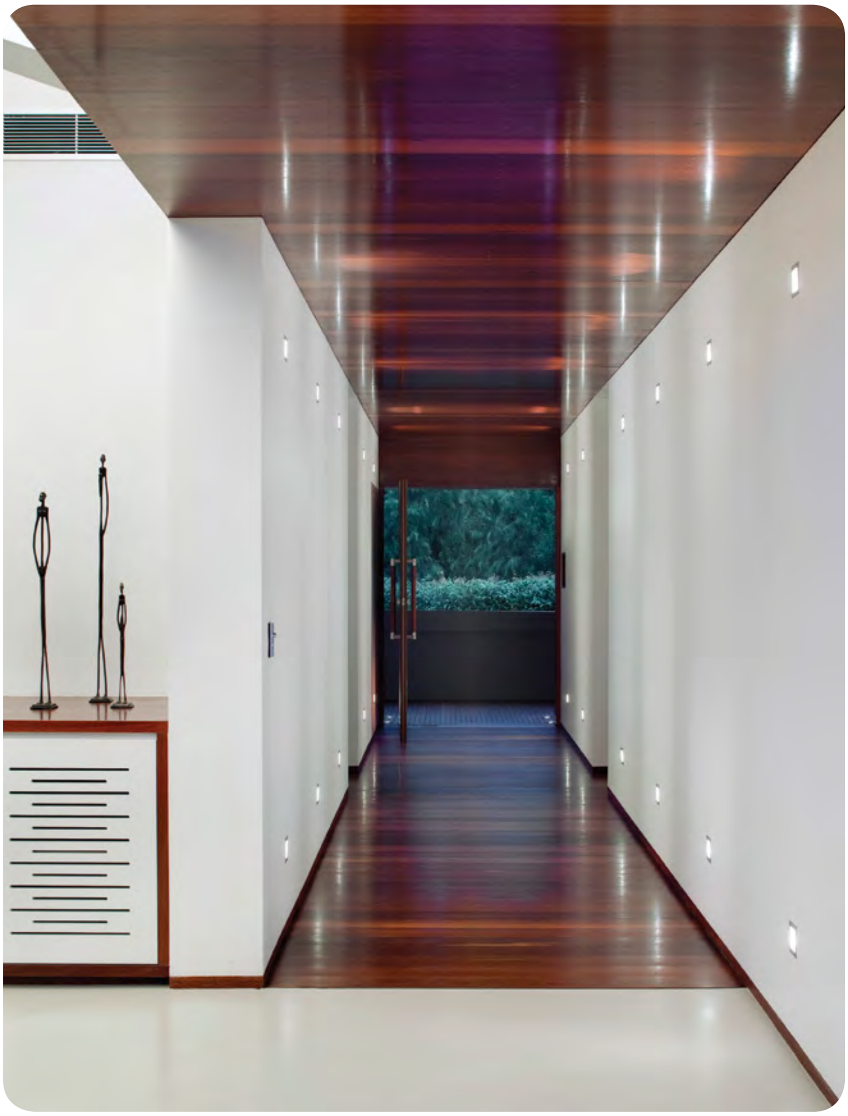
Timber Products

Timber is available in a wide range of products, from unprocessed natural rounds, to more highly processed laminated veneer products. Each product has its own properties and uses in internal design.

Commonly available products include:

- solid sawn and moulded timber for structural elements, furniture, screens and panels, skirtings and architraves (new or recycled timber);
- glue laminated timber (glulam) for structural elements, and bench tops;
- veneer for decorative wall panels, furniture, and joinery;
- plywood and laminated veneer lumber (LVL) for cladding, furniture, joinery, structural elements, etc; and
- engineered wood panels, such as medium density fibreboard (MDF) and particleboard for cupboard carcassing, and veneer substrate.

This section presents information on each of the key timber product types as summary tables for reference.



CplusC Design Construct: Queens Park Residence.

4.1 Solid Timber: Local hardwoods

Left: Matt Chan, Scale Architecture, with Katie Hepworth and Isabel Cordeiro: Infinity Forest.

Right: Peter O'Gorman and Brit Andressen, Mooloomba House. Photo by John Gollings.

Description

Solid sections timber converted from native Australian hardwood species.

Uses

- Flooring
- Internal lining
- Furniture and joinery
- Stairs and handrails
- Windows, doors and screens
- Architectural and concealed structures
- External cladding

Comments

- Available in many species from certified sources
- Local variation in species
- Broad colour range from light brown to dark reds
- Dry density from approximately 600 to 1100kg/m3
- Available rough sawn, dressed or moulded
- Natural features and figure
- Can be durable

Grades

Appearance grades to AS 2796

Select-Low feature Standard- Medium Feature High Feature

Milling requirements are consistent across the three grades.

Structural grades: seasoned

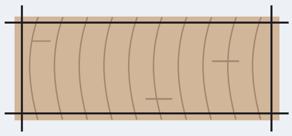
Visually graded to AS 2082:

F8 → **F27**

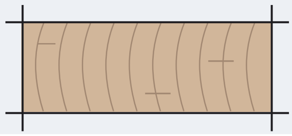
Increasing strength & stiffness

Typical Sizes

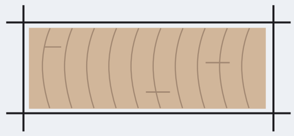
Sawn
Size off the saw overcut to allow for shrinkage during drying to the nominal dimensions.



Nominal
Dry, rough sawn size. Thickness of 25, 38 & 50 mm.
Widths of 75, 100, 125, 150, 175, 200+.

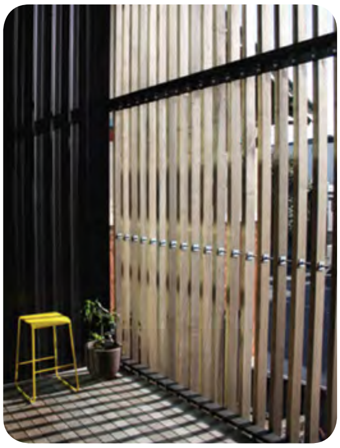


Machined
Dry, milled size will vary with producer and products.
Common sizes are: Thicknesses of 19, 32, 35 & 45 mm
Widths of 65, 70, 85, 90, 115, 135, 140, 165, 185+



Hardwoods are the dominant species group in Australia's native forests. Local hardwoods have been used widely in Australia since European colonisation for internal finishes and lining, envelope elements such as windows and doors, and external structures and cladding. In recent years, local hardwood production has increasingly focused on seasoned appearance material for applications such as floors, joinery and furniture. At the same time, designers are increasingly exploiting the timber's grain and feature.

NH Architecture and Woods Bagot: Hilton Convention Centre, Southbank.



Chris Tate Architecture: Slat House.

Bligh Voller Neild: GOA Image House.

Squillace Nicholas Architects: Black Stump Restaurant.

Smith + Tracey: Olinda Tea House.
Interior wall panelling in service and during construction.

4.2 Solid Timber: Local softwoods

Left: Lecturn, St Patricks Cathedral

Right: David Boyle Architect: Burridge Read Residence

Description

Solid sections timber converted from native Australian and introduced softwood species

Uses

- Flooring
- Internal lining
- Furniture and joinery
- Stairs and handrails
- Windows, doors and screens
- Architectural and concealed structures
- External cladding

Comments

- Available in many species from certified sources
- Local variation in species
- Colour range from creams to medium browns
- Dry density from approximately 350 to 550 kg/m^3
- Available rough sawn, dressed or moulded
- Natural features and figure
- Can be durable but generally less durable than local hardwoods

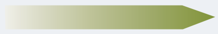
Grades

Appearance grades from clear to utility

Select grade celery top pine at Saffire resort, Tasmania

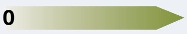
Structural grades: seasoned

Visually graded to AS 2082:

F8  **F27**

Increasing strength & stiffness

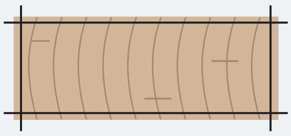
Machine graded to AS 3519:

MGP10  **MGP15**

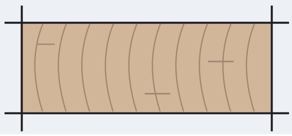
Increasing strength & stiffness

Typical Sizes

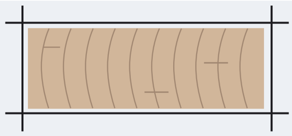
Sawn
Size off the saw overcut to allow for shrinkage during drying to the nominal dimensions.



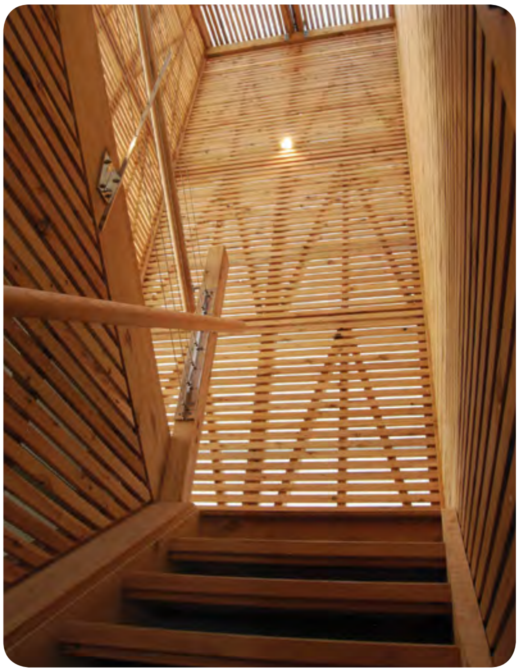
Nominal
Dry, rough sawn size. Thickness of 25, 38 & 50 mm.
Widths of 75, 100, 125, 150, 175, 200+.



Machined
Dry, milled size will vary with producer and products.
Common sizes are: Thicknesses of 18, 19, 21, 32, 35, 45 mm
Widths of 66, 92, 110, 116, 138 , 170, 190+.



Grant Amon Architects Pty Ltd: Svarmisk Resort Centre, NZ.



Troppo Architects, SA: Whale of a Beach House.

4.3 Solid Timber: Imported

Left: American White Oak

Right: American Oak

Description

Solid timber sections imported from overseas. Major sources include Europe, North America, and south-east Asia.

Uses

- Flooring
- Internal lining
- Furniture and joinery
- Stairs and handrails
- Windows, doors and screens
- Architectural structures
- External cladding

Comments

- Many species available from international sources
- Procure from certified sources, especially species from high-risk countries
- Usually high quality appearance and finishing material in a variety of colours
- Most commonly available in seasoned and unseasoned rough sawn boards and less frequently in seasoned dressed boards
- Regional species supply and application preferences exist

Grades

Appearance grades from clear to utility
Appearance grades and terminology vary with the timber's origin but often include a low feature or premium grade and grades with higher feature.

Structural grades: seasoned

Visually graded to AS 2082 (hardwood) and AS 2858 (softwood):

F5 → **F27**

Increasing strength & stiffness

Softwoods machine graded to AS 3519:

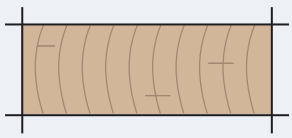
MGP10 → **MGP15**

Increasing strength & stiffness

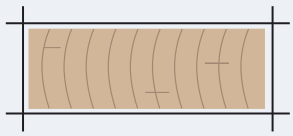
Typical Sizes

Sizes vary with the country of original production.

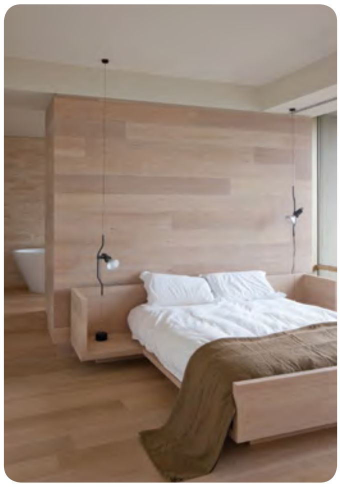
Nominal
Common dry, rough sawn sizes are:
Thickness of 25, 38, 50, 65 & 75 mm
Widths of 63, 75, 100, 125, 150, 200+



Machined
Dry, milled size will vary with producer and products.
Common sizes are: Thicknesses of 19, 32, 42, 54, 65 mm
Widths of 54,65, 90, 110, 140 , 190+



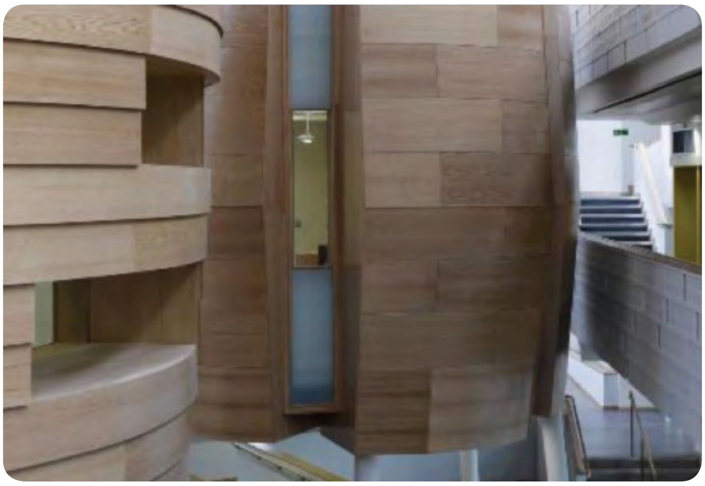
Britton Timbers: Cambia Ash Lining.



Jolson: Albert Road Apartment.

Jackson Clements Burrows: Henley Street.

Jolson: Albert Road Apartment.



Britton Timbers: American Red Oak.

4.4 Glue-laminated Timber

Description

Glue-laminated timber (glulam) is assembled by gluing together small pieces of timber, known as laminates, to produce large sizes and long lengths. The individual laminates are usually finger-jointed into continuous lengths, removing significant defects, and then assembled into the final piece.

Uses

- Stairs and handrails elements
- Top and slab elements in joinery and furniture
- Wind posts for windows and glazed walls
- Beam and column elements in architectural and concealed structures

Comments

- Can be curved or straight
- Large section sizes and long lengths can be manufactured
- Stronger than solid timber of the same size
- Dimensionally stable
- Works easily with all the usual carpentry tools
- Both standard and customs sections can be made

Grades

Appearance grades
(by structural grade and quality of fabrication/finish)

Structural grades

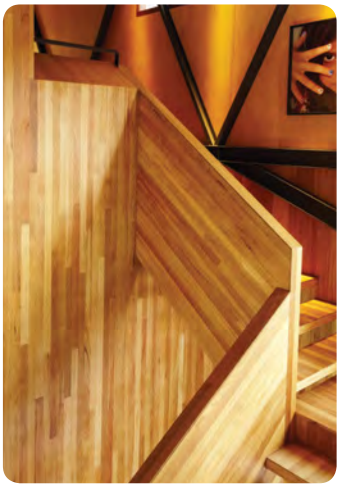
Graded to:
GL8 → **GL18**
Increasing strength & stiffness

Typical Sizes

Radiata pine	
Width	**Depth**
65mm	130, 165, 195, 230, 260, 295, 330, 360, 395, 425mm
85mm	130, 165, 195, 230, 260, 295, 330, 360, 395, 425, 460+mm
135mm	130, 165, 195, 230, 260, 295, 330, 360, 395, 425, 460+mm

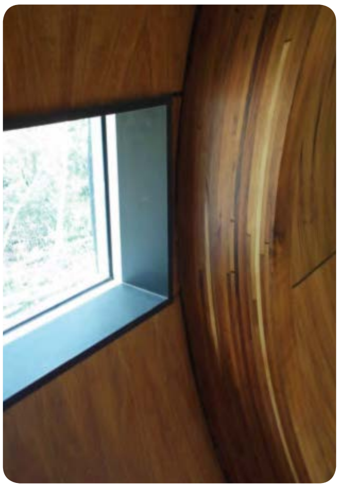
Hardwood	
Width	**Depth**
45mm	120, 140, 170, 190, 222, 240, 290mm
65mm	120, 155, 185, 215, 245, 270, 300, 330, 360, 390, 420, 450, 480mm
85mm	120, 155, 185, 215, 245, 270, 300, 330, 360, 390, 420, 450, 480mm
135mm	120, 155, 185, 215, 245, 270, 300, 330, 360, 390, 420, 450, 480mm

2011 Timber Awards: The St Kilda West Project.



Bureau SRH: The Birdcage.

David Luck Architecture: Cloud Chamber.



Dismal Swamp.

Berlina Projects: Lilypad.

4.5 Decorative Veneers

Left: Veneer leaf.

Right: Andrew Macdonald: Stirling St Residence.

Description

Decorative veneer is a thin slice of wood cut from the wood. It can be peeled from logs or sliced from flitches into sheets or leaves at a predetermined thickness and grain orientation. Veneer is available in leaf or adhered to a substrate or backing.

Uses	Comments
• Internal lining • Stair handrails • Furniture and joinery • Doors and screens	• Available in many local and imported, softwood and hardwood species in a wide variety of colours and grain patterns • Efficient use of feature wood • Veneer has a tight and loose side and should be laid with the tight side outwards • Can be glued up into flat, bent and curved panels • Substrate must be dry at 8 to 10% MC at gluing

Appearance grade

Veneers are usually graded into face and backing grade veneers. Generally, face grades have strict limits on natural features.

Typical Sizes

Veneer leaf is often about 2.5 m long, with varying widths between bundles of leaf. Leaf is often assembled into layons that match the length and width of board substrates.

The size of specialist and high-feature veneer is limited by the occurrence of the feature in the log.

4.6 Plywood

Right: Ashton Raggatt McDougall (ARM) – Vos Construction: Melbourne Recital Centre

Description

Plywood is a timber panel product assembled from veneers of timber glued together so that the grain of alternate layers is at right angles to each other.

Uses

- Flooring
- Internal wall and ceiling lining
- Substrate for appearance veneers
- Furniture, fittings and joinery
- Stairs and handrails
- Doors and screens
- Architectural structures
- Concealed bracing panels and shear skins
- External cladding

Comments

- Dimensionally stable
- Available from softwoods and hardwood
- The numbers and thickness of veneers varies with the quality and intended use of the product. There is always an odd number of veneers.
- Large variation in visual and structural quality available – see manufacturers
- Appearance grade veneers can be applied to the surface

Grades

Appearance grade To AS 2270

Highest quality **Lowest quality**

A grade.

B grade.

C grade.

D grade.

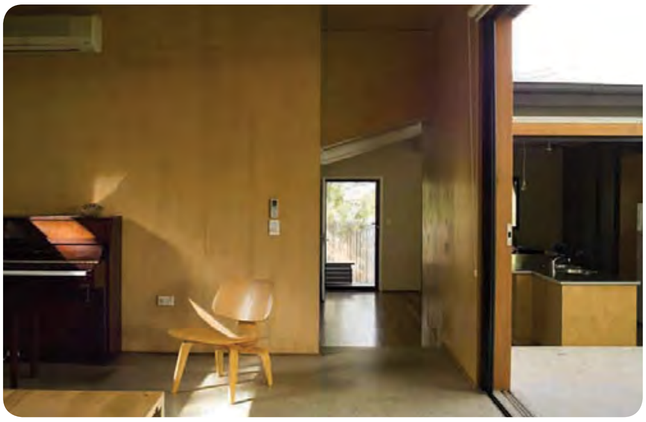
Bond type
A - dark colour. Internal or external use
B - colourless. Internal or external use
C & D - light colour. Internal use only

Structural grades To use with AS1720

Graded to:
F7 → **F34**
Increasing strength & stiffness

Typical Sizes

Lengths: 1800 mm, 2100 mm
Widths: 900 mm, 1200 mm
Thicknesses: 3, 4, 6, 12, 15, 17 mm



Casey Brown Architecture: Bungan Beach House.

Dale Jones Evans Architecture with Marchese & Partners: M Central.

Plus Architecture: Office.

Wood Solutions – Internal stairs.

4.7 Laminated Veneer Lumber

Tim Hill: Office Development Surrey Hills.

Description

Laminated veneer lumber (LVL) is a structural wood product manufactured from peeled veneers laminated into a panel with the grain of most veneers running parallel to each other along the board for structural strength. The few cross veneers increase section dimensional stability.

Uses

- Bench tops and slabs
- Stairs and handrails
- Structural beam and column elements in architectural and concealed structures

Comments

- Dimensionally stable
- Large variation in visual and structural quality available – see manufacturers
- Generally manufactured from softwood, mainly Radiata Pine
- Not available in appearance grades but can accept an appearance veneer

Grades

Appearance (by structural grade)

End/edge grain

Structural grades

By manufacturer to AS/NZS 4357

Typical Sizes

45 mm x depths in mm* 150, 200, 245, 300, 360
63 mm x depths in mm* 150, 200, 245, 300, 360
Potentially available up to 13 m long x 1.2 m wide x 75 mm thick
45 mm lengths (m) 3.0 to 8.4 in 0.3 increments then 9.0 m, 9.6 m, 10.2 m, 12.0 m
63 mm lengths (m) 3.0 to 6.0 in 0.3 increments then 6.6 m, 12.0 m in 0.6 m increments

Seeley Architects: Citriodora

Spowers Architects:
Williamstown High School.

Bureau SRH: The Birdcage.

4.8 Engineered Fibre/Chip/Strand Board

Matt Gibson Architecture and Design.

Description

Board elements made from: timber fibres bonded together in a dry process such as medium density fibre board (MDF) to AS/NZS 1859.2-2004; fibres bonded in a wet process such as softboard or hardboard to AS 1859.4; chips such as chipboard (particleboard) to AS/NZS 1859.1-2004; or strands such as oriented strand board (OSB).

Uses

- Internal lining
- Carcassing
- Not available with appearance grades
- Structural bracing (hardboard and OSB)

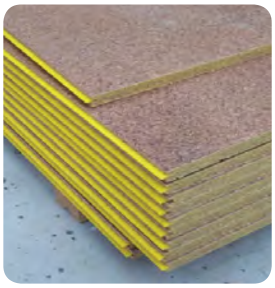
Comments

- Typically bonded with adhesive except Masonite hardboard
- Available in water resistant boards
- Easily machined
- Smooth/good surface integrity
- Uniform thickness and properties
- Very stable (little risk of warping)
- Edges not suitable for coating

Grades

Appearance

Medium density fibreboard.



Particleboard.

Structural grades

By manufacturer, if applicable

Typical Sizes

Board Type	Width	Length	Thickness
Softboard	900, 1200 mm	2400, 3200 mm	12, 15, 18 mm
Hardboard	900, 1200 mm	2400, 3200 mm	3, 6, 9, 12 mm
Medium Density Fibreboard (MDF)*	900, 1200 mm	2400, 3200 mm	3 to 25 mm
OSB/Particleboard	900, 1200 mm	2400, 3200 mm	12, 15, 19 mm

*Moisture Resistant (MR)

Matt Gibson Architecture and Design: The Coop - structure and cladding constructed from LVL Beams and OSB Panelling.

Morris-Nunn and Associate: Scottsdale Forest EcoCentre.

David Boyle Architect: Burridge Read Residence.

5

Interior Design Elements

This chapter presents information tables on the use of timber internally by application type, ordered in decreasing size.

Architectural structures feature the architectural expression of structure within an internal space. Expression of structural elements can be the key to a successful holistic design solution in many projects, with visual character of a space being influenced by the structural form required.

Lining is the finishing material on the internal wall or ceiling surfaces of a room or space. While linings can be utilitarian or merely a substrate for paint, as is plasterboard, they can also be significant elements in an architectural design or an interior fit out.

As a lining material, timber in one of its various forms and arrangements can:

- enhance appearance and visual interest
- improve acoustic and thermal performance
- reduce maintenance.

Flooring is visually significant part of any interior space. With an extensive range of colours, textures and forms, the architectural potential for timber flooring is extensive. To achieve this potential and create long lasting and stable timber flooring, the main design and specification requirements are:

- selecting species hard enough for the intended use;
- ensuring adequate insulation and sound separation;
- determining the correct moisture content for the project;
- keeping moisture away from the timber in application; and
- choosing the correct finish for the floor.

Stairs and handrails are visually significant vertical elements in any building design, defining the flow of space and movement between different levels. The inherent risks in their uses and their function as means of escape in a fire building regulations limit the general parameters of the stair design.

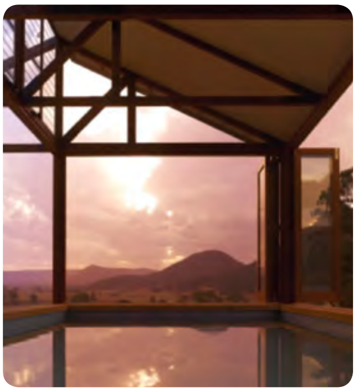
Windows and doors are special elements in any building design. Windows and doors are often visible internally and externally. Their form and proportion are fundamental to the appreciation of the elevation and massing outside, and perceptions of spatial arrangement inside. Windows affect the comfort and amenity of inhabitants significantly, controlling ventilation, introducing natural light and influencing thermal performance.

Furniture and joinery are some of the most intricate and valuable uses of timber in any aspect of building. Both share the demand for a high quality of finish and visual appeal, tactility, and functionality. Furniture has the extra requirement of portability.

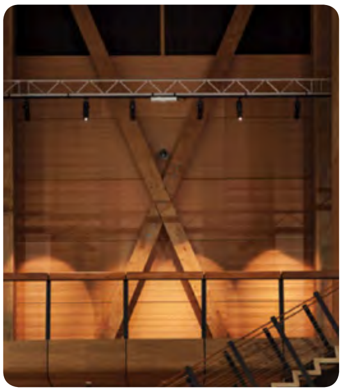
External elements associated with interior design are typically spaces where the inside seamlessly transitions to the outside. Timber used externally requires very careful specification and detailing.

Mouldings were traditionally used as functional yet ornate elements such as picture and dado rails, to protect plaster in areas susceptible to damage such as skirtings, or to cover construction tolerance and junctions such as architraves around doors. Contemporary mouldings tend to simpler than ornate historic mouldings.

5.1 Architectural Structures



Turner and Associates Architects: Wolgan Valley Resort and Spa.



Studio Pacific Architecture: Holmes Consulting Group.

Berlina Projects: LilyPad.

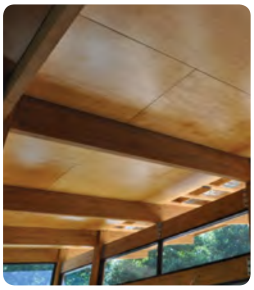
Description

Skilled use of timber in architectural structures leads to unrivalled interior spaces. There is a large range of structural options available which can be expressed internally. The following examples relate to the main types and forms. Consult a structural engineer for more information.

Timber is used in exposed architectural structures because it provides:

- **Design versatility**. A wide range of timber materials and solutions are available for spans up to and over 100 m.
- **Ease of construction.** There are a wide range of simple and effective jointing systems. Timber solutions are also light, simplifying erection.
- **Honesty of expression.** As a natural material, the varying strength characteristics in timber often force a direct and honest expression of force and load. This can establish a clear structural expression.
- **High strength-to-weight ratio.** Timber is very light for its strength. This makes for efficient structures and easier construction.
- **Economy.** Due to materials cost, workability and ease of construction, timber structures have historically been cheaper to build and vary than comparable steel and concrete buildings.

Design options



Post and beam is a relatively simple but very useful structural system suitable for general multi-storey construction.

Rafters - In addition to sitting on posts, beams can span between walls. This can be as a single span or continuous over more than one span.

Trusses are frames of members, typically in a single plane, joined only at their end and interconnected to form triangles. They are generally deeper than solid members, and they place material efficiently in the form.

Domes/grids are complex surfaces with double curvature divided into a triangular grid. The triangular grid is then formed using straight timber elements connected at nodes. Timber elements tend to be glulam or LVL.

5.2 Internal Lining: Stick elements


Volker Haug and Maddison Architects: Ludlow Foundation.

Description

Solid sawn timber cut into regularly sized and generally rectangular pieces or profiled into tongue and groove boards.

Uses

Residential, commercial, industrial walling or ceilings

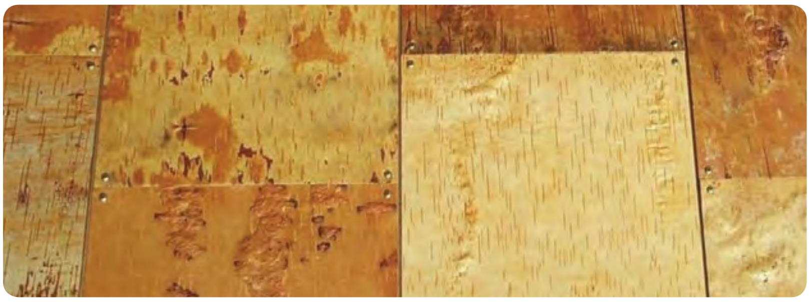
Comments

- Can be rough sawn or dressed to a smooth finish.
- Appearance products are sorted into visual grades, such as Select or Standard grade.

Design options

Solid timber boards fixed to frame or battens, butted, lapped, or slatted (vertical or horizontal or diagonal). Boards can vary in, size, proportion, species, finish and texture. Manipulating the ratio of board to gap and the backing colour can add another level of articulation.

Woods Bagot and NH Architecture: Hilton Convention Centre.



Description

Engineered timber panels or selected decorative veneers laid on a sheet substrate and mounted onto battens on a wall or ceiling.

- Interior plywood: non-structural appearance product suitable for internal wall panelling, furniture and fittings, interior door skins and ceiling lining. Bending plywood is relatively simple. Plywood can be cut or have its surface machined with computer-controlled routing equipment allowing complex patterns to be realised.
- Particleboard: smooth, good surface integrity, uniform thickness, uniform properties and good dimensional stability, and excellent substrate for high grade veneer.
- Medium density fibreboard (MDF): widely used as a substrate material due its smooth surface and edge-finishing qualities. Good substrate for high grade veneer.
- Hardboard: typically used in the backing of cabinetry. Hardboard tends to have a very smooth side and a side textured with lines around 3 mm long.

Uses

- Residential
- Commercial
- Industrial
- Walling or ceilings

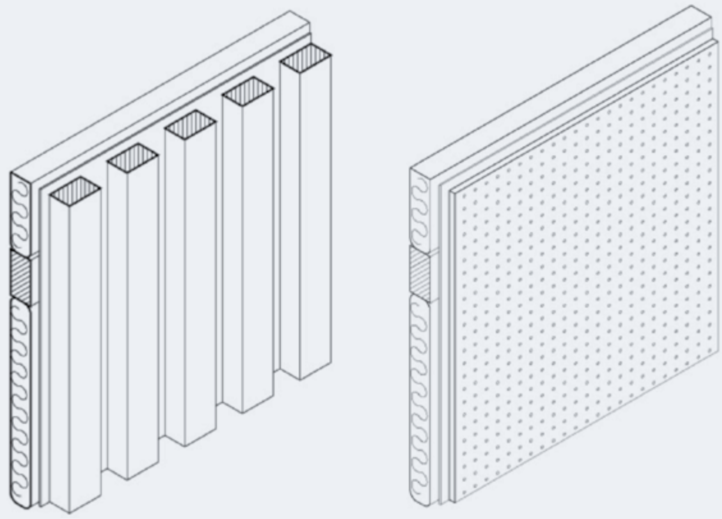
Design options

- Fixed to frame
- Fixings concealed or exposed
- Joints flush, lapped or with shadow ‘gap’
- Hung on sub-frame fixed to frame; for prefabrication of high quality panels
- Book matched, slip matched or random veneer options

Jaime Kleinert Architects: Persephone Investments.

Campbell Drake: Dusk Bar.

5.4 Internal Lining: Sound control



Description

A system of visually expressed timber elements with perforations or gaps with acoustic absorbing material behind.

Uses

- Offices
- Auditoria
- Industrial

Design options

- Sound absorbing lining, in combination with stick or panel elements, alter the reverberation time in a space, improving sound quality.
- Perforated sheet materials: veneered plasterboard, veneered particleboard, plywood or MDF requires about 10% perforation to perform efficiently with the acoustic absorber. The size of the perforations can be adjusted to manipulate the acoustic properties.
- Slatted boards as an acoustic panel: boards spaced on frame with fabric backing/insulation for sound absorption.

5.5 Internal Lining: Partitions and screens

2010 Timber Award Australia Post

Description

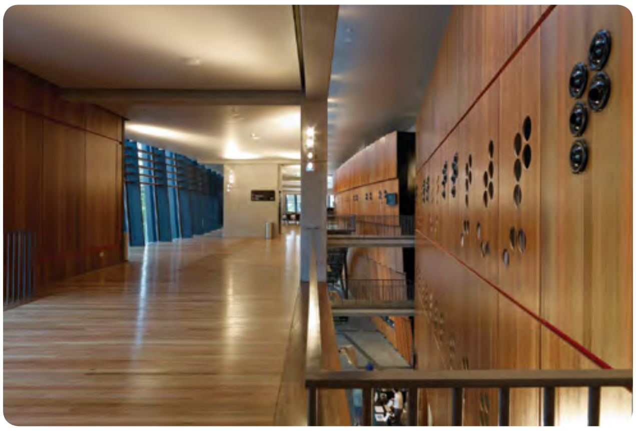
Solid timber elements or engineered timber products arranged to create screens or partitions which may be floor to ceiling part-storey height.

Uses

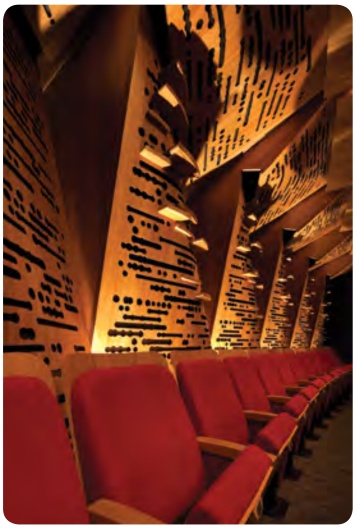
- Offices
- Auditoria
- Industrial
- Residential

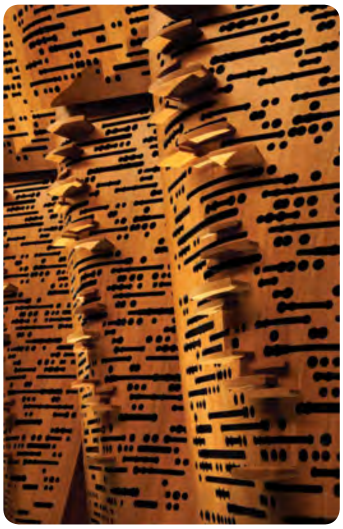
Design options

- Can incorporate storage space with shelves and cupboards Sound absorbing lining in combination with stick or panel elements can be provided.
- May be opaque or provide borrowed light between spaces.



Tonkin Zulaikha Greer: Glasshouse – Arts, Conference and Entertainment Centre.

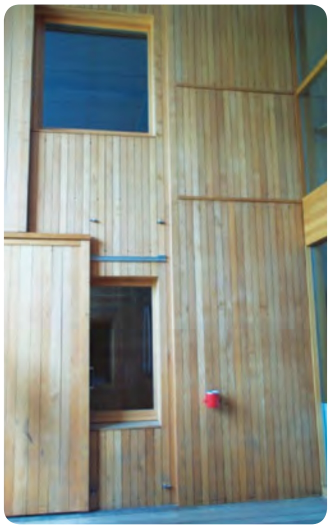




*Tonkin Zulaikha Greer: Glasshouse –
Arts, Conference and Entertainment Centre.*

Bureau SRH: The Birdcage.

Studio Pacific Architecture with Warren and Mahoney: The Rock



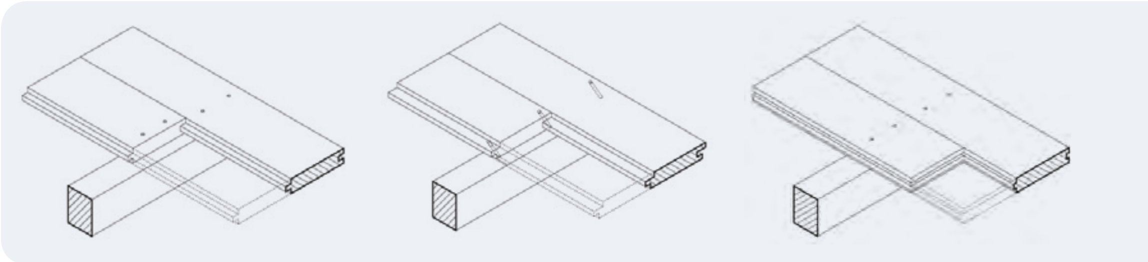
*School of Architecture,
Wood and Civil Engineering,
Biel, Switzerland*

Sibelius Centre, Lathi, Finland

Siren Design: AGL Headquarters

5.6 Flooring: Standard strip

Installation methods



Surface nailed: face or exposed nailed.

Secret nailed: nails to be hidden as they are driven through the extended tongue of the board as the individual boards are laid.

End matched: tongue or groove on all four sides of the board to eliminate the necessity to locate joints directly over floor joists.

Description

Interlocking tongue and groove (also known as T&G) boards assembled into a structural floor over joists or battens. Timber boards available in many species, typically hardwood. Janka hardness required >5 kN for domestic and >7 kN for commercial. More information is available in *WoodSolutions Guide #9 Timber Flooring – Design guide for installation* or from the Australian Timber Floor Association (ATFA).

Uses

- Residential
- Commercial
- Industrial

Comments

- Detail to allow for movement with changing moisture content. See *WoodSolutions Guide #9 Timber Flooring – Design guide for installation*
- Can be re-finished and repaired, ensuring longevity.

Typical size

- Width 65 – 133 mm
- Thickness 19 mm min (450 mm joist span)

Installation

- Joist level deviation to be less than 3 mm per 3 m
- Boards should span at least three joists
- Cramp <800 mm
- Machine driven nails 50 x 2.8 mm for softwood joists, 50 x 2.8 mm for hardwood joists (AS 1684)

5.7 Flooring: Overlay strip

Description

Interlocking tongue and groove (T&G) assembled as a finish over a structural substrate. Boards are available in many solid timber species or engineered from species such as bamboo or from fibre or chipboard. Janka hardness required >5 kN for domestic and >7 kN for commercial. More information is available in *Wood Solutions Guide #9 Timber Flooring – Design guide for installation.* Overlay strip flooring can be:

- floating floor, where the floor is held down by the skirtings;
- nail only floor, where the boards are nailed to a plywood or wood product substrate; or
- glued floor, in which the boards are glued with specialist elastomeric adhesive, and possibly nailed to the substrate.

Uses

- Residential, commercial & industrial
- Floating floors in gymnasia
- Acoustically resilient layers for sound separation

Substrate options

- Plywood
- Chipboard
- Plywood underlay on concrete
- Concrete

Typical size

- Width up to 85 mm
- Thickness 12-15 mm

Comments

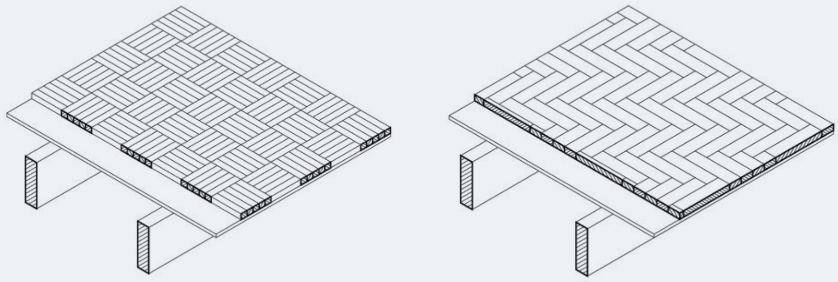
- Floating or bonded.
- Boards are available for use in any of the T&G profiles described above.
- Overlay flooring can be fixed either by nailing, gluing, or gluing and nailing.
- Detailed to allow expansion at the edges – 10 mm per 6 m width of flooring.

5.8 Flooring: Overlay parquetry

Description

Small pieces of timber, known as fingers, glued as a finish onto a suitable structural substrate, such as a sheet material (plywood or chipboard) or concrete.

- Mosaic parquetry: panels of small thin timber pieces arranged in a selected pattern, glued to a backing material.
- Block parquetry: individual pieces thicker than parquetry pieces.
- End grain parquetry: trafficked surface is end-grain, i.e. the end of the 'bundle of straws' faces upwards.



Uses

- Residential
- Commercial
- Industrial

Substrate options

- Plywood
- Chipboard
- Plywood underlay on concrete

Typical size

- Mosaic: approximately 130 x 20 x 10 mm
- Block: range from 340 x 85 x 20 mm to 260 x 65 x 20 mm

Comments

- Available with surface embossing that improves traction underfoot.
- Purchased as a pre-arranged pattern adhered to a backing sheet or as loose pieces that can be arranged into a pattern on site.
- Compatible species or grade of the pieces can also vary or be mixed to create patterns of colours or tones.

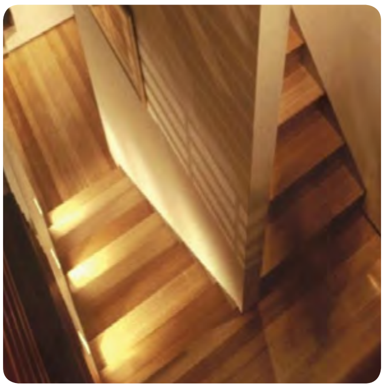

Seeley Architects: Citriodora.


Seeley Architects: 13th House.


Marsh Cashman Koolhoos Architects: MG House.


BMW Edge Theatre, Federation Square.

5.9 Stairs and Handrails



Lincolne-Lomax: Studio and Gallery

Walter Barda Design: The Boatshed.

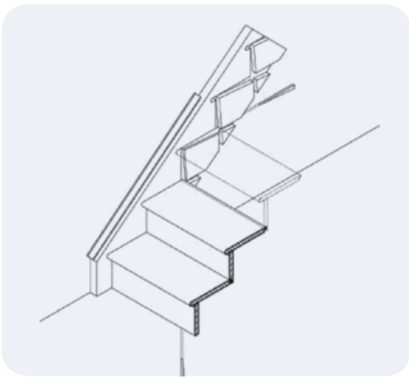
Description

Solid timber elements or engineered wood products crafted into structures which tend to be visually significant in interior spaces. The requirements for stairs and handrails can be found in the National Construction Code Building Code of Australia (BCA). Typically, the size of risers and goings are limited and there is restriction on the relationship between the two. A single step in a floor is prohibited. A flight of stairs must have a minimum of two risers and a maximum of 18 before a landing is included. The riser height must not change in a flight. The diameter and tread sizes in circular stairs are also restricted. Handrails are required. Gaps between the treads of any open stair and balusters in any handrail are restricted to reduce injury to small children. More information can be found in the *Wood Solutions Guide #8 Stairs, Balustrades and Handrails.*

Uses

- Inside to outside
- Residential
- Commercial
- Fire (means of escape)

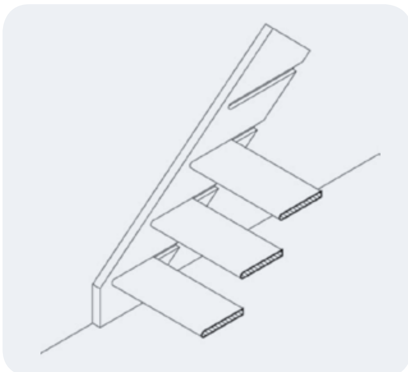
Design options



Enclosed

Treads and risers rebated into stringer

Treads and risers supported on additional framing

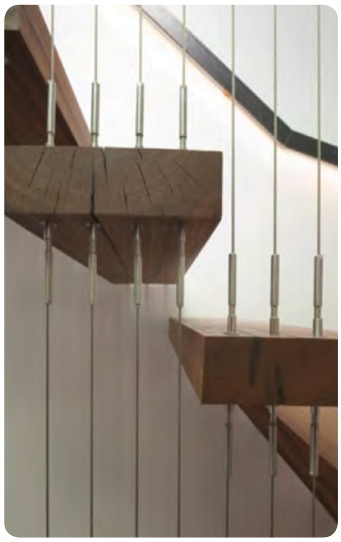


Open

Treads and risers rebated into stringer

Treads and risers supported on additional framing

Mark Pearse Architect.



Sam Crawford Architects: Newtown Terrace.

Woodhead: Pernod Ricard Corporate Office.

Phillips/Pilkington Architects: MADEC Wesley Centre.

Scale Architecture: Milis Salem House.

5.10 Windows and Doors

School of Forestry, Lyss, Switzerland, Clinton Cole.

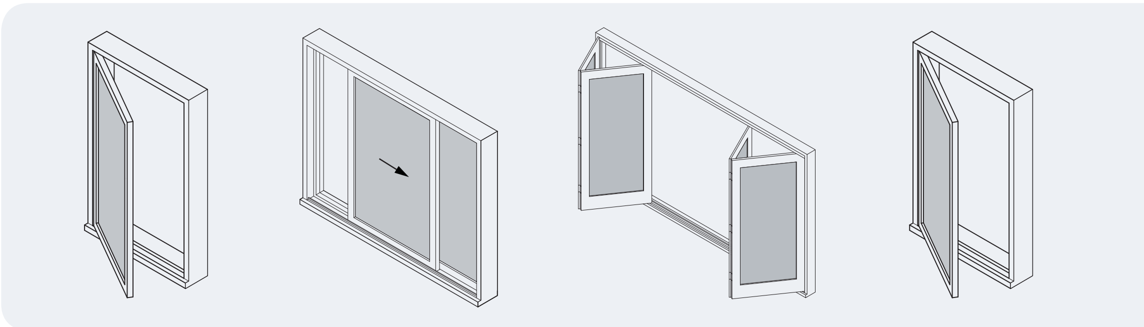
Description

The detailed design and specification of windows and doors includes externally exposed timber elements.

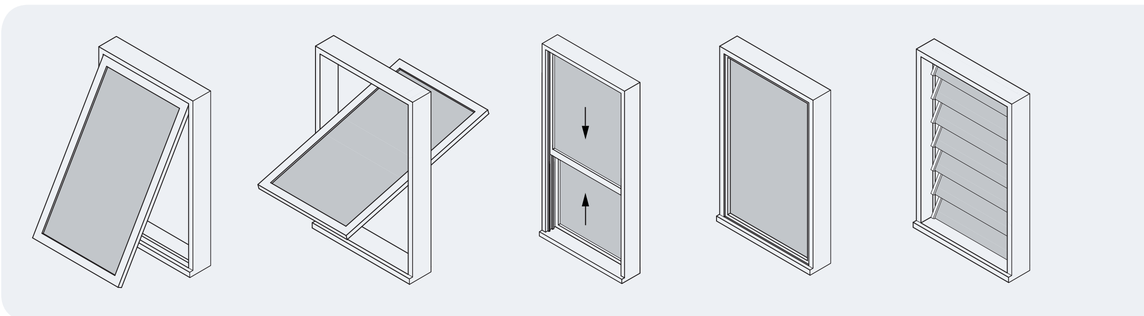
The use of timber externally is a vast and detailed topic covered elsewhere in documents such as *Wood Solutions Guide #10 Timber Windows and Doors*. As a summary, the key considerations in the design and specification of windows and doors are:

- Durability of the timber elements: timber species and/or treatment should be appropriately selected to have required durability for the exposure anticipated for different parts of the window or door.
- Stability of the window frame: timber species, timber cut and or wood product should be selected to minimise movement and distortion of the window frame with changes of moisture content in manufacture and service.

Design options



Casement window/ hinged door ***Sliding window/door*** ***Bi-fold window/door*** ***Pivot window/door***



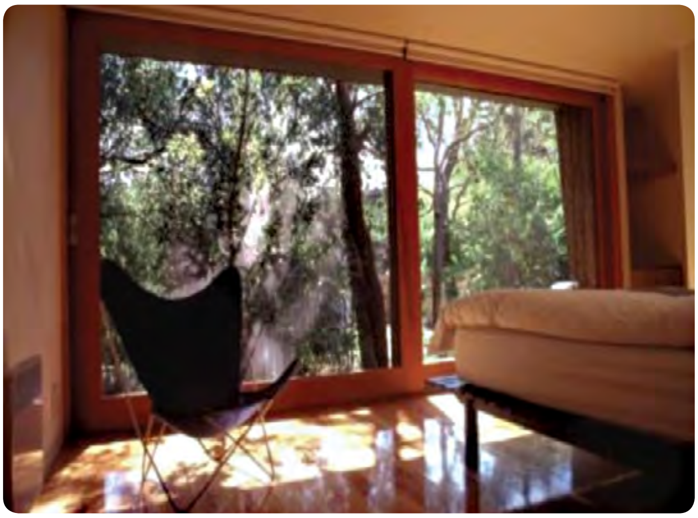
Awning window ***Pivot window*** ***Sash window*** ***Fixed window*** ***Louvre window***

Virginia Kerridge Architect: House in country NSW.

Architects EAT: Linear House.

Richard Cole Architects: Cottage Point.

MCK Architects: Flipped House.



John Wardle Architects: Isaacson/Davis Beach House.

Brewster Hjorth:
Freshwater House.

5.11 Furniture and Joinery

Britton Timbers

Timber Award: Cottage Point House.

Description

Furniture and joinery is subject to close inspection by the eye and touch of the hand. It generally demands a higher level of finish and connection than other elements of internal design. The quality of the material, design and assembly must match these demands.

Joinery is the detailed functional elements of a building such as benches, cupboards and doors which are fixed to the building's structure. The required quality of assembly and finish in joinery ranges from simple and utilitarian to levels rivalling fine furniture.

Design options (by material)

Solid timber

Bentwood

Glue-laminated

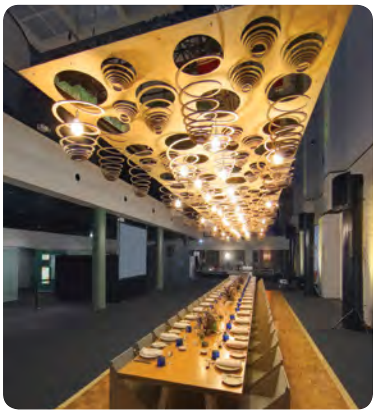
Plywood

Particle/fibre board

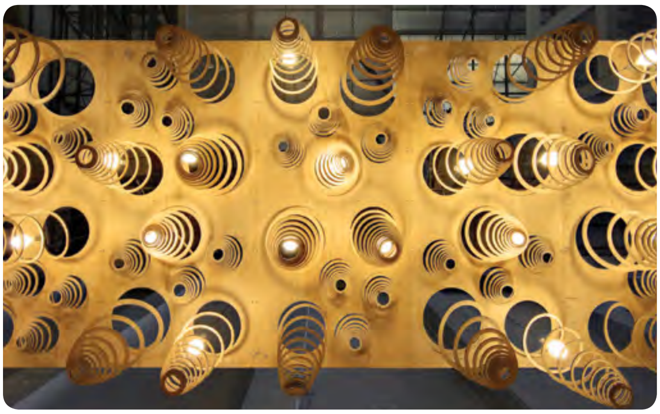
Veneer

Bovis Lend Lease offices, Melbourne.

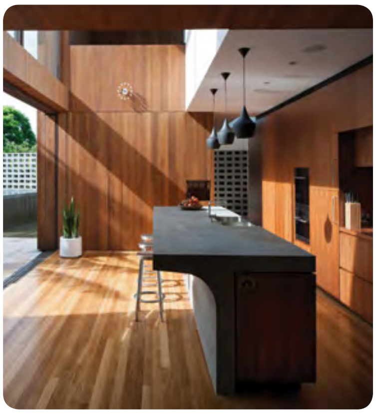
Facet Studio - Habitat Antique



Tribe Studio: Eat Green Design



Tribe Studio: Eat Green Design



MCK Architects: The Flipped House.

Architects: Citriodora.

5.12 External Elements

John Wardle Architects: Queenscliff Residence.

Description

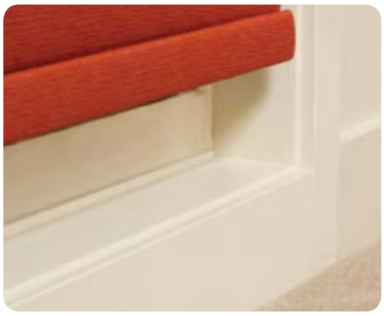
The use of timber in external structures is a vast and complex topic covered elsewhere in great detail in many documents including *Wood Solutions Guide #5 Timber Service Life Design – Design guide for durability* and *Wood Solutions Guide #13 Finishing Timber Externally*. In summary, external elements must be designed for durability of structural and visual characteristics through appropriate selection of species, finishes and connection details. Key considerations are durability of timber, coating/treatment of timber, connection design to shed water, discoloration under UV exposure, and differential colour change with weathering under non-uniform exposure.

Design options

Internal External

David Boyle Architect: Burridge Read Residence.

5.13 Mouldings



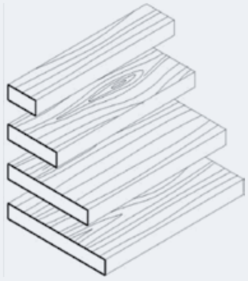
Description

Timber mouldings were traditionally used in areas prone to damage, such as skirtings, or areas to take tolerance in building, such as architraves and cornices. Elements are typically solid timber but can be from engineered timber such as MDF. Many standard profiles are available, though any prismatic section can be made if required.

Design options

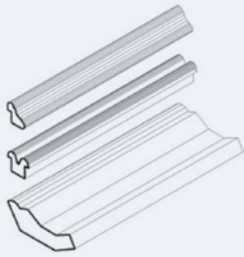
Rectangular timber sections

Used often as contemporary skirting and architraves.



Specialty/ornate mouldings

These are moulded to almost any shape for use as cornices, picture rails, trims, etc.



Splayed boards

Splayed material is widely used in architraves, skirtings and trims.

6

Material Basics

This chapter provides a basic understanding of how the natural characteristics of wood can influence timber end-products for use in internal applications.

6.1 Wood Structure

The structure of wood at a cellular level, and the way in which the cells are grown in succession, give the visual character to a piece of timber. The cells which form the grain of the wood are like long hollow tubes that run up the trunk of the tree. This can be seen in the:

- **Grain:** the pattern and orientation of the cells along the length of a piece.
- **Growth rings:** the radial patterns of wood of varying density laid down in each season and most visible on a cut end.

The physical properties of wood vary, whether along the grain fibres or across them, radial to the log centre or tangential with a growth ring. The variation in physical properties governs the way in which timber is orientated in application. For example, the strength parallel to the grain fibres is around 10 times that perpendicular to the fibres, which is why column (post) elements are loaded parallel to the grain.

As well as varying with direction relative to grain, the character of timber obtained from a tree varies with:

- **Species and genetics:** trees come from various species and the character of each species is different. This includes differences in colour, hardness, durability, grain and feature. These features make unique timber products regarded as a valuable commodity and highly sought after material.
- **Climate and arrangement:** trees of the same species and genetic background grown in different climates and arrangements produce timber with different character. This provides variety in the same species which is a natural quality and characteristic of timber.
- **Location within tree**: the properties and visual characteristics of timber obtained vary within individual trees with the age of the wood and whether the wood grew under stress.

Commercial timbers are normally broadly classified into two main groups: hardwoods and softwoods. Species such as eucalypts and oaks are hardwoods. Softwood includes pines, spruces, firs and other conifers. The terms 'softwood' and 'hardwood' do not always indicate the softness or hardness of the timber. In fact, many hardwoods are softer and lighter than some softwoods. For example, balsa is botanically classified as a hardwood, but is well known to be soft and lightweight. Generally, hardwoods are adopted in applications requiring harder-wearing surfaces, increased durability, strength or stiffness.

The differences between the cell structures of hardwoods and softwoods influence their aesthetic qualities.

Flowering angioperms.

Open seeded gymnosperms.

The differences between the cell structures of hardwoods and softwoods influence their aesthetic qualities. Hardwoods have vessels. Vessels are large cells used to transport water within the plant. Softwoods have a more uniform structure than hardwoods. The visual characteristics of each are described in Section 2.2.

6.1.1 Moisture

It is critical to understand the relationship between water and timber to successfully specify and use timber in interior applications. Under ordinary conditions, all wood contains some water. The amount of water contained in wood at a particular time – its moisture content (MC). The moisture content of a piece of timber is defined as the weight of water contained in the piece expressed as a percentage of its oven dry weight.

Drying splits in a log.

Drying kiln.

Moisture meter.

Moisture content at conversion

When the timber has been freshly converted from a tree it is termed 'green'. Typically, the timber would then be dried or 'seasoned' to a moisture content aligned with that anticipated in-service – generally between 9% and 18% MC. Drying timber increases its value and versatility by improving its dimensional stability, strength, stiffness, durability, insulating characteristics, and workability.

As timber dries from green to its in-service moisture content, it shrinks. Shrinkage occurs on a predictable basis, with a uniform change in dimension in each of its three principal directions (longitudinal, tangential and radial) per percentage point change in moisture content. Timber sections can be distorted because timber shrinks at different rates as it dries whether tangential and radial to growth rings or parallel to grain.

The term 'unit shrinkage' is defined as the percentage change in dimension following a moisture content change of 1%. Unit shrinkage (or movement) is an important property for timber in high-value applications. It gives an indication of the dimensional changes that may be expected in timber in response to environmental changes, such as the movement in floorboards between summer and winter. Shrinkage characteristics of some commonly used species are found in Table 2. More species information can be found through the WoodSolutions website.

Table 2: Shrinkage rates.

Shrinkage	Shrinkage from FSP to 12% MC	Species and Unit Shrinkage
Very High	Tangential >8.0% Radial >5.0%	Brush box (0.38) Vic ash (0.36) Forest red gum(0.34) Sydney blue gum(0.35) Tas Oak (0.36)
High	Tangential 6.5% - 8.0% Radial 4.0% - 5.0%	Blackbutt (0.37) Jarrah (0.30) Rose gum (0.30)
Medium	Tangential 5.0% - 6.5% Radial 3.0% - 4.0%	Radiata pine (0.27) Spotted gum (0.38) Tallowwood (0.37) Red ironbark (0.37)
Low	Tangential 3.5% - 5.0% Radial 2% - 3.0%	Hoop pine (0.23) Slash pine (0.30) Blackwood (0.27)
Very Low	Tangential 0% - 3.5% Radial 0% - 2.0%	White cypress (0.26)

Moisture content in application

After initially drying from 'green', timber will continue to lose moisture and shrink, or gain moisture and expand, to be in equilibrium with its surrounding environment. The moisture content at equilibrium is known as the equilibrium moisture content (EMC). The equilibrium moisture content will vary with the internal environment in which the timber is placed. For an air-conditioned space the EMC will be around 9%, though will vary with species. More typically timber in an internal space will reach EMC at about 12%.

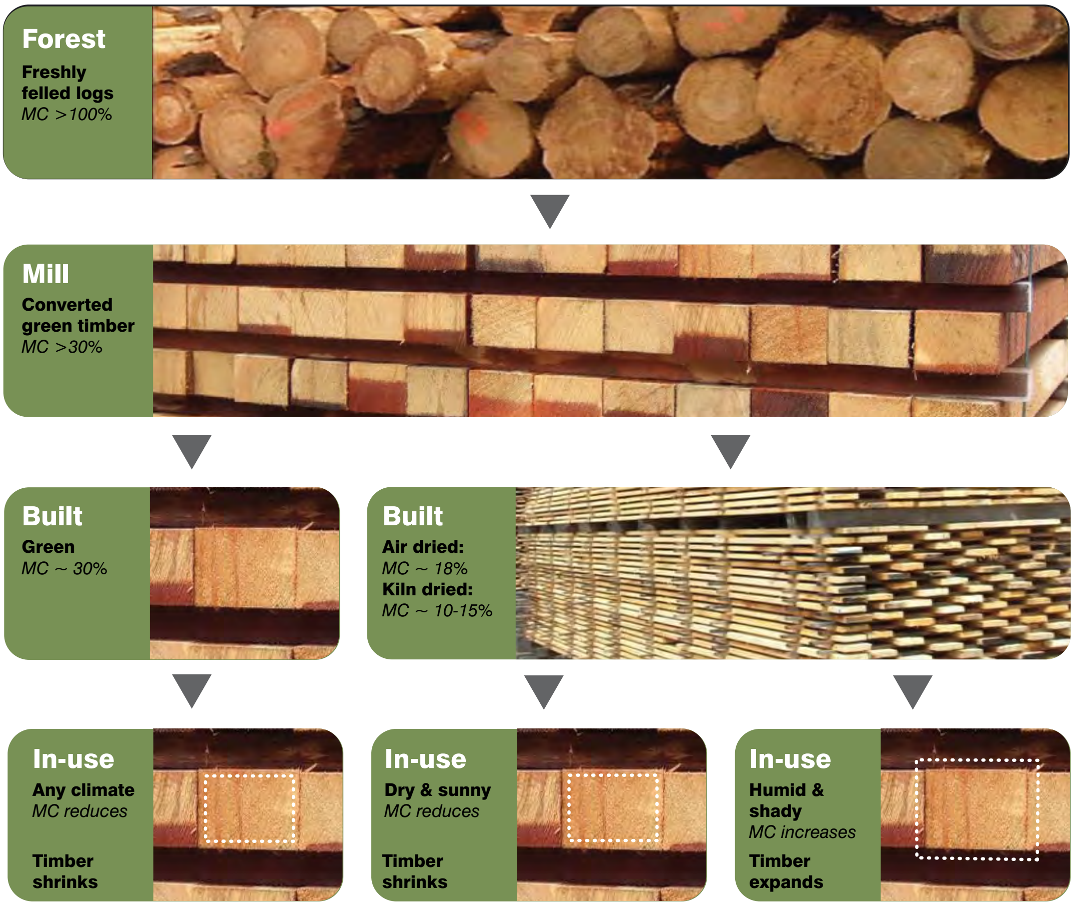


Figure 5: Changing moisture content through production and use.

Humidity and temperature within an internal space may change on a daily basis as well as on a seasonal basis but because of timber's relatively slow response rate it is only influenced by longer cycles such as seasonal. The effects of seasonal changes may be observed in a timber floor or windows. Gaps between adjoining boards in the floor will open and close at different times of the year and a window may jam during a wet season.

The response rate of softwoods such as Hoop Pine or Radiata Pine is more rapid than that of the denser hardwoods such Spotted Gum, Brushbox or Victorian Ash. Even within the hardwood or softwood groups, response rates can also vary quite markedly.

Ongoing dimensional change of an element once installed is an inherent natural property of wood associated with environmental changes on a regular basis. These changes are predictable and the responsibility for accommodating them in internal application rests with:

- the designer/architect/specifier ensuring the material specified is appropriate and that the predicted movement in application has been accounted for;
- the contractor in providing adequate protection to ensure the moisture at the time of installation is as anticipated in application;
- the building user by following best practice maintenance.

7

Satisfying Performance Requirements

Timber and timber products used in internal applications are typically selected for their visual characteristics. As such, it is critical that the visual characteristics are maintained in application throughout the design life of the element. Maintaining this visual character requires:

- **correct specification of timber grade;**
- **resistance to indentation and abrasion;**
- **durability and resistance to bio-deterioration;**
- **structural performance; and**
- **fire performance.**

7.1 Timber Grading

Grading is the production process of sorting products into groups with similar characteristics and properties. Material is graded to agreed standards which can be nationally or internationally recognised standards, or for large orders and specialist projects, developed between producers and customers. The agreed specification between designer and producer can often be more restrictive than Australian or International Standards, defining all facets of the product including colour range or types of natural feature.

Products governed by visual characteristics, which are selected based on appearance, are sorted into visual grades, such as Select or Standard Grade. These are termed 'appearance grades'. Structural sections are graded into 'stress grades', such as F17 or MGP10, by visual or mechanical means. Stress graded timber will in certain interior applications be visually expressed. In such a case, it is prudent for the interior designer to become familiar with the visual characteristics of the different stress grades to assess aesthetic appeal. The designer may also wish to impose an appearance grade requirement on the stress graded timber.

Visual grading.

7.2 Solid Timber Appearance Grading

Solid timber is visually graded into appearance grades to a set of rules established by:

- **Australian Standards**: These cover major commercial products such as flooring, and lining timbers. For example: *AS 2796-1999 Timber – Hardwood – Sawn and milled products, AS 1810-1995 Timber – Seasoned cypress pine – Milled products* and *AS 4785-2002 Timber – Softwood – Sawn and milled products. AS 2082-2007 Timber – Hardwood – Visually stress-graded for structural purposes* and *AS 2858-2008 Timber – Softwood – Visually stress-graded for structural purposes* provide guidance on visually stress grading timber for structural purposes.
- **Industry standards:** These cover furniture stock, joinery, cabinetry and similar material. These are often established between a producer and a major customer. For example, they may set the type and amount of feature required in the timber.
- **Industry service providers:** The *FWPA Interim Industry Standard Recycled Timber – Visually Graded Recycled Decorative Products* and *FWPA PN06.1039 – Recycled Timber – Visually Stress Graded Recycled Timber for Structural Purposes* provide guidance on visually grading reclaimed, recycled timber for various uses from linings to structural elements.
- **Designer specification:** Like industry standards, they are often established between a designer and particular producer for a specific project or group of projects. Such a specification would usually be developed for large orders on large projects.
- **Personal selection:** Defined by the individual on a case-by-case basis.

The solid timber grades are Select, Medium feature and High Feature.

Australian standard AS 2796 defines three major product grades: Select, Medium Feature/Standard, and High Feature, examples of which are presented below and on the solid timber summary sheet in Section 5. The grades are separated by the amount of natural and production-induced characteristics found in each board. Each grade has permissible limits different growth phenomenon, which are described in more detail in Section 8.2. Colour or colour consistency is not a criterion. Allowable tolerance from machining is consistent between grades. Specification of grades with fewer permissible features, such as Select, will lead to lower utilisation of the timber obtained from a tree.

The grades can be summarised as follows:

- **Select:** Straight and even grain timber with fairly uniform texture and limited amounts of natural feature, such as gum, knots and hobnail.
- **Medium Feature/Standard:** Even grain timber with increased amounts of natural feature providing a surface with distinct natural appeal.
- **High Feature:** Timber with regular quantities of natural feature with a distinct rich, lively and vibrant surface.

Select.

Standard.

High feature.

Unlike Select, and to a lesser extent Standard grade material, High Feature boards are really a mixture of several visual sets. This grade can often be re-sorted or industry grade established so that particular features become more prominent on the finished surface.

AS 4785-2002 Timber – Softwood – Sawn and milled products is similar in product requirements and visual grades to AS 2796. AS 4785 has established visual grades of Clear, Appearance, Select, Standard and Utility Grade. For Radiata pine there is a much greater use of industry defined grades with appearance and so the terms for particular visual combinations can vary between companies.

7.3 Plywood Grading

Plywood manufactured to AS 2270 in Australia has either a Type C or Type D bond, which is typically light in colour. Both bonds are durable under fully protected interior environments but are non-durable under full exposure to weather or to wet or damp environments. Type C bonded interior plywood should be used in high humidity areas such as bathrooms, and in the tropics. Type D bonded interior plywood is satisfactory for interior applications under normal humidity conditions. Structural plywood generally has waterproof Type A & B bonds and can be used either internally and externally. Type A bonds are typically dark in colour. Type B bonds are colourless. Images of plywood bond colours can be found in Section 5.

Black bond type A.

Marine grade.

Interior grade.

Structural grade.

Plywood can be ordered and procured with face veneers suitable for the intended application. The face grades available are:

- A – a high quality appearance grade suitable for clear finishing.
- S – a decorative face veneer that permits natural timber characteristics such as knots.
- B – a grade that provides a suitable substrate for high quality painted finishes.
- C – a non-appearance grade with solid surface, i.e. all open defects are filled.
- D – a grade that can have open defects and is normally used as a back veneer.

AD grade plywood, which has one face grade A and one grade D, would be specified for a clear finished aesthetic application requiring one good surface. Structural plywood normally has C and D grade faces, but can be specially ordered with higher quality face veneer. Face quality examples are included below for guidance only.

A grade.

S grade.

B grade.

C grade.

D grade.

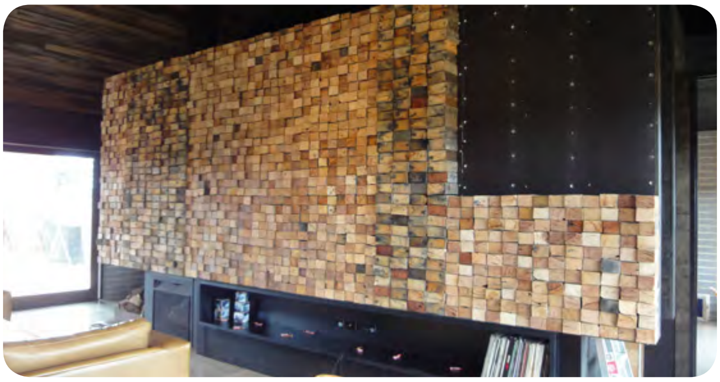
7.4 Veneers Grading

Detailed requirements for veneers used for the manufacture of veneered panels are specified in the Australian/New Zealand Standard AS/NZS 1859-1996 Reconstituted Wood-Based Panels, Part 3: Decorative Overlaid Wood Panels. Grading rules described in this standard have been adopted by the Australian veneer industry and they are widely used when specifying veneered boards.

7.5 Tolerance

An acceptable level of tolerance is codified as an allowable deviation from the sectional dimensions and length, and deviation from straightness and planarity. AS 2796 defines acceptable amounts of bow, spring, cup and the target moisture content for the major product groups in material of different product types. Tolerance limits relate to deviation immediately after machining, and do not relate to movements which may occur in-service.

Tolerances are established for the major product groups including joinery and dressed boards; strip and overlay flooring, mouldings, sawn boards and light decking, lining boards, cladding, fascia and bargeboards.

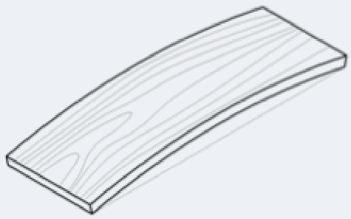


Wolveridge Architects: Hill Plains House.

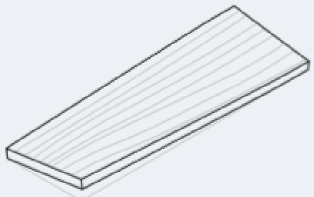
AS 2796 defines acceptable amounts of bow, spring, cup and the target moisture content for the major product groups.

Description

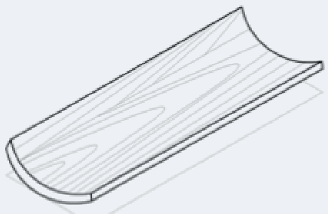
Bow is a curvature in the longitudinal direction of a board causing the wide face to move away from a flat plane. Bow is specified with respect to board thickness.



Twist is spiral distortion along the length of a piece of timber. Twist is specified with separate limits for less or more than 25 mm thick.



Cup is a concave or convex curvature across the grain or width of a piece of timber. Cup is typically limited to less than 1 mm per 100 mm width.



Spring is a longitudinal curvature of the edge of a piece of timber, not affecting the face. Spring is specified with respect to board width.

7.6 Hardness

The ability of a timber species to resist indentation in use is determined by its hardness. Hardness varies between species. Hardness is typically determined by the Janka hardness test and represented in kiloNewtons (kN). Hardness is particularly critical for floors and bench-tops. For example, for all but domestic flooring applications, a hardness of at least the same as Victorian ash (about 5) is required. A hardness of above 7 is preferable for any commercial flooring application.

7.7 Durability

Durability of timber is its natural resistance to bio-deterioration caused by fungi, insects and mechanical breakdown (e.g. weathering, checking and splitting). Durability is species dependent. The heartwood of each species is more durable than the sapwood. Durability in internal applications is not as critical as for external applications. More information on durable species can be found in Australian Standard AS 5604-2003 and *Wood Solutions Guide #5 Timber Service Life Design Guide*.

7.8 Structural performance

Timber elements specified based on structural performance will be designed according to AS 1684 Residential Timber Framed Construction for domestic scale structures or to *AS1720 Timber Structures Part 1: Design Methods for larger structures*. The structural elements will then be specified according to structural grade. Different structural grades have different visual characteristics with higher grade structural material tending to have fewer features, such as knots and sloping grain, than lower grades. Architectural structures will often be designed such that the structural elements are exposed in the internal space. In such a case the designer should review the visual qualities of the proposed structural grade and work with the design team to ensure intended visual qualities are achieved.

Circa Morris-Nunn Walker: Saffire during construction and completion.

7.9 Fire

More fire performance resources are available for download from woodsolutions.com.au

Adequate performance of timber structures and finishes is ensured by following the National Construction Code Building Code of Australia (BCA). Detailed information can be found in *Wood Solutions Guide #3 Timber-framed Construction for Commercial Buildings Class 5, 6, 9a & 9b, #2 Timber-framed Construction for Multi-residential Buildings Class 2, 3 & 9c, #1 Timber-framed Construction for Townhouse Buildings Class 1a* and *#4 Building withTimber in Bushfire-prone Areas.* Visually expressed large section solid timber, glue-laminated timber or laminated veneer lumber can be designed to achieve a required fire resistance level (FRL) in accordance with *AS1720.4-2006 Timber structures Part 4: Fire resistance for structural adequacy of timber members.*

7.10 Resistance to Chemicals

Timber is resistant to all but the strongest alkalis and acids (pH>10 and pH<2). In strong acid and alkali environments, such as science laboratories, the rate of degradation is dependent on many factors such as species, chemical and exposure. Discussions with the client on a project-by-project basis will determine likely risk level.

Adhesives used for wood products, such as glulam and plywood, which rely on a bonding agent for structural capacity, are typically robust enough for the majority of common applications. However, specialist advice should be sought if the environment in which the timber is to be used has an extreme ambient environment.

References

Australian Standards AS/NZS 1859-2005 *Reconstituted wood-based panels - Specifications - Decorative overlaid wood panels.*

Australian Standards *AS 1684.2-2010 Residential Timber Framed Construction.*

Australian Standards *AS 2796-1999 Timber - Hardwood - Sawn and milled products.*

Australian Standards *AS 2082-2007 Timber - Hardwood - Visually stress-graded for structural purposes.*

Australian Standards *AS 5604-2005 Timber - Natural durability ratings.*

Australian Standards *AS 1810-1995 Timber - Seasoned cypress pine - Milled products.*

Australian Standards *AS 4785-2002 Timber - Softwood – Sawn and milled products.*

Australian Standards *AS 2858-2008 Timber - Softwood - Visually stress-graded for structural purposes.*

Australian Standards *AS 1720.1- 2010 Timber Structures Part 1: Design Methods.*

Australian Standards *AS 1720.4-2006 Timber structures Part 4: Fire resistance for structural adequacy of timber members.*

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Wood Solutions Guide #4 Building with Timber in Bushfire-prone Areas, 2011.

Wood Solutions Guide #5 Timber Service Life Design Guide, 2011.

Wood Solutions Guide #8 Stairs, Balustrades and Handrails, 2011.

Wood Solutions Guide #9 Timber Flooring, 2011.


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Fire Design

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Introduction

Despite public perceptions to the contrary, timber buildings can be designed to be very safe in fires and other emergencies. Designing for fire safety must enable people to escape in the early stages of a fire, and provide fire resistance to prevent a fire spreading and the building collapsing.[1]

This Guide provides a summary of fire safety design process for a number of EXPAN-developed systems, including timber concrete composite (TCC) floors, timber cassette floors and post-tensioned timber beams without any fire-rated lining or additional protection.

Design for structural stability in fire conditions is covered, as well as worked examples of the fire safety design procedures for each system. To get the best out of this Guide, it should be read in conjunction with AS/NZS 1720.4 and *WoodSolutions Technical Design Guide #17: Alternative Solution Fire Compliance.*

1.1 Fire safety – Fire Resistance Levels

The Building Code of Australia Deemed-to-Satisfy Provisions specifies fire resistance in terms of Fire Resistance Level (FRL). The required fire resistance will depend on the building's height, occupation use, the inclusion of sprinklers, escape pathways and other factors. The fire resistance may differ from the requirements of the prescriptive Deemed-to-Satisfy Provisions in the Building Code if a professional fire engineer provides a specific fire engineering design, leading to a Performance Solution design.

The required fire resistance is expressed in terms of Structural Adequacy, Insulation and Integrity for a specific time period that element is required to protect. Protection times vary from 60 to 120 minutes for various elements and situations in a building.

1.2 Fire Resistance Criteria

The National Construction Code –Building Code of Australia[2] (NCC BCA) and most others around the world specify fire resistance in terms of three criteria: Stability, Insulation and Integrity. The BCA calls this criteria the Fire Resistance Level (FRL). These categories are concerned with preventing the structural collapse of the element, preventing the transmission of fire and smoke through the element, and preventing unacceptable levels of heat being transmitted through the element.

For example, a specified FRL of 60/60/60 requires that all three criteria equate to 60 minutes exposure to a standard test fire, a time and temperature curve specified by AS 1530.4.

Design for Stability is required for structural walls and floors, as well as for isolated beams and columns. Calculations or tests must be used to show that the structural member can carry the applied loads for the full duration of the fire exposure without collapse or excessive deformation.

Design for Insulation and Integrity is required for containment elements, such as walls and floors, to prevent unwanted spread of fire within or between buildings. Design for Integrity and Insulation is not required when considering isolated structural members such as beams or columns.

1.2.1 Determining Fire Resistance Level

The NCC BCA has several methods to determine Fire Resistance Level, detailed in Schedule 5. In essence, there are three methods available for timber. The first method is via a test to AS 1540.4. AS 1540.4 requires a full-scale test that exposes the porotype element to a standard fire test for the relevant time period, measuring the time it takes to obtain failure of Stability, Integrity or Insulation. Another method is based on calculations performed on the test outcome, derived from the full-scale test of the prototype. This is normally done by a Registered Test Authority and generally relates to variations to span or height, or thickness and so on. The third method is also a calculation method, carried out via a reference Standard AS/NZS 1720.4. This method is applicable to certain engineered wood products only and is explained further in Section 1.4.1.

1.2.2 Fire Design for Stability

Design for Stability requires the structure to remain in place after fire exposure and still be able to support a load. The applied load under fire conditions is less than the standard structural load used to check Stability and strength as specified in the AS 1170 series of Australian Standards, as it is not expected that the full load will be in place during a fire. Therefore, fire design load is the full permanent load plus a fraction of the total imposed load, usually 40%.

When an exposed timber element is subjected to fire, a char layer forms that insulates the unburned material and reduces the subsequent rate of charring. For structural fire resistance, the timber element in the buildings may have many hours of fire resistance that can be determined from a full-scale test to AS 1530.4 or calculated using AS/NZS 1720.4 effective depth of charring calculation method. The latter method is based on a notional charring rate that is dependent on the density of the timber element at 12% moisture content. The density of engineered wood products is based on the dominate timber species not the element itself, which may have adhesive included. Design guidance is given in this Guide.

1.2.3 Fire Design for Integrity

Design for Integrity is required for containment elements, such as walls and floors, to prevent unwanted spread of fire between fire compartments or buildings. It is not required when considering isolated structural members such as beams or columns. Design for Integrity can only be determined from a full-scale test to AS 1530.4, as AS/NZS 1720.4 has no calculation method. For many timber mass systems, the joints between panels are the crucial point of failure. Design for Integrity requires that there must be no gaps or openings that allow flames or hot gases to pass through the member during the fire exposure period. Gap size may also be affected by deflection of the element during fire exposure; consequently, this should be considered in the design.

1.2.4 Fire Design for Insulation

Design for Insulation requires that the temperature rise on the unexposed surface of the barrier to be kept to a level that will not ignite objects on the non-fire side and allows for the building occupants to escape past the fire-resisting element without being impaired by high temperatures. Again, this can be determined from a full-scale test to AS 1530.4, where it requires the cold side of the barrier must not exceed the initial temperature by an average of 140°K or a peak of 180°K at the end of the fire exposure time.

Alternative AS/NZS 1720.4 provides a method via empirical data that has shown over many tests that a residual cross-section, after the nominated fire resistance period, is to be a minimum thickness of 30 mm.

1.3 Fire Hazard Properties

Safety in the initial stages of a fire depends on the fire hazard performance of covering materials. The building codes restrict the covering used in building, depending on its occupation, location in the building and whether fire sprinklers are installed. Exposed timber elements may be considered as coverings, and there may be additional limitations in the NCC BCA Deemed-to-Satisfy Provisions. Refer the NCC BCA[2] for further information.

1.4 Fire Resistance: Design of Timber Members by AS/NZS 1720.4

AS/NZS 1720.4 is a primary reference within the NCC BCA and can be used to determine the Fire Resistance Levels of a timber element.

1.4.1 Timber Products Subject to AS/NZS 1720.4

AS/NZS 1720.4 is not applicable to all timber products; it is appropriate for sawn timber, timber in the pole form, plywood, laminated veneer lumber (LVL) and glue-laminated timber. In addition, the timber product must meet the relevant Australian grading Standard for structural purposes; and for engineered timber, use adhesives that are either phenol, resorcinol, phenol-resorcinol or poly-phenolic structural adhesives. Timber products outside this scope can only use the full-scale prototype testing method AS 1530.4 to determining Fire Resistance Levels.

1.4.2 Design Procedure of AS/NZS 1720.4

The purpose of AS/NZS 1720.4 is to calculate the residual cross-section are of a timber element after exposure to a fire for a specific period of time. Failure of structural timber members in fires results from a loss of cross-sectional area rather than a loss of strength due to heating. This behaviour is due to timber's inherent insulating nature, which ensures that the penetration of heat into the timber section and the rate at which it chars is slow. When a timber member is exposed to fire, a char layer forms on its outer perimeter, which inhibits further combustion and heating of the remaining timber section except for a small zone immediately in front of the char layer.

The charring rate of timber varies due to its density, moisture content and grain direction, as well as the intensity of the fire. Higher-density timber chars slower than lower-density timber. The residual section of a timber member under a particular fire loading can be found by subtracting a thickness equal to the charring rate multiplied by the fire resistance period (in minutes) from each side of the member that is exposed to the fire, plus an additional depth to account for the heat-affected zone ahead of the char layer.

The main design steps for all structural timber elements, including beams, columns, floors, frames and walls, are:

1. Calculate the effective depth of char for the required fire resistance period.
2. Add the specified zero-strength layer to allow for heated wood below the char.
3. Calculate the size of the residual cross-section.
4. Design the residual timber section for flexure, axial load and shear strength using the fire load, loading case in AS 1170.0.
5. Include crushing and buckling calculations for any members with axial load.
6. Check the bearing area of elements to prevent bearing failure.

1.4.3 Determining the Structural Stability

The effective residual section is determined by subtracting the calculated *effective depth of charring* from all fire-exposed surfaces of the timber member. When determining the effective residual section, corner charring can be ignored.

The designer must check whether the residual section will withstand the design load for the period of required fire resistance, under the reduced load combinations specified by AS 1170.0, Section 4.2.4 as $G + \psi_l Q$ and any action arising from thermal effects.

In normal Stability and strength design, the timber element used in the horizontal orientation is typically governed by deflection limits, not strength. AS/NZS 1720.4 does not provide any advice on deflection, leaving it the decision of the design engineer. Other than collapse issues, the designer must consider the effect that deflection may have on joints and junction of elements within the timber building. Excessive deflection will cause gaps that will cause integrity failure. As a minimum, the deflection of the elements under fire load conditions should not be less than span/30.

Notional Charring Rate

AS/NZ 1720.4 has three methods to determine the notional charring rate:

- prescriptive notional charring rates for common timber species
- calculation method based on the timber specie's density
- notional charring rate determine from prototype test.

AS/NZS 1720.4 provides the notional charring rate of common timber species (see Table 1).

Table 1 – Notional Charring rates for common timber species.

Timber Species	Notional charring rate mm/minute
Blackbutt	0.50
Cypress	0.56
Douglas fir	0.65
European spruce	0.65
Spotted gum	0.46
Grey Ironbark	0.46
Red Ironbark	0.47
Jarrah	0.52
Merbau (Kwila)	0.51
Radiata pine	0.65
Victorian ash and Tasmanian oak	0.59

Calculation method for Notional Charring rate

AS/NZS 1720.4 provides the calculations method based on the timber species density at a moisture content of 12% in kg/m^3. The notional charring rate by the following equation:

$$C = 0.4 + (280/D)^2 \qquad (1.1)$$

where

C = notional charring rate in mm/min

D = timber density at a moisture content of 12% in kg/m^3

The average timber density of the base timber species at 12% moisture content can be found from AS 1684, AS 1720.1 and the WoodSolutions website. For engineered timber products, the published density (AS 1684, AS 1720,1 and the WoodSolutions website) of the timber species used predominately in the makeup of the element must be used. The actual density of the engineered timber is not used as it contains a component of adhesives that generally increases its density. For plywood and LVL products, the density at 12% moisture content of the timber species used to manufacture the product should be used.

Effective Depth of charring (de) calculated by:

$$d_c = C.t + 7.0 \qquad (1.2)$$

where

d_c = calculated effective depth of charring in mm

C = notional charring rate in mm/min, calculated above

t = period of time, in minutes.

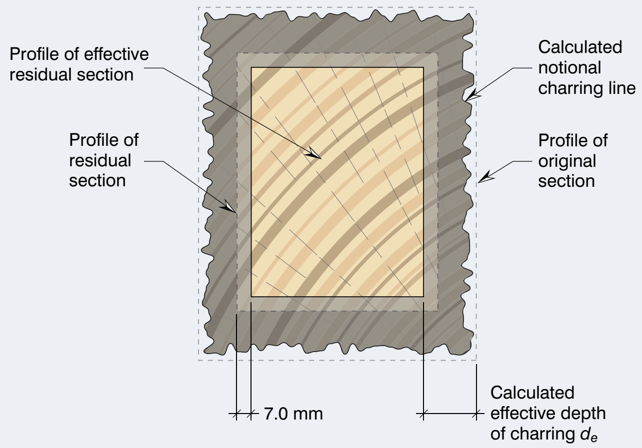

Figure 1.1: Char to timber element.

AS/NZS 1720.4 provides a test method to determine the national charring rate of individual timber species. The test method is based on AS 1530.4 test method and uses a 1,000 x 1,000 mm minimum size furnace that exposes a specimen of at least 75 mm thick to the Standard Fire test curve. The orientation of the specimen is essential as test sample orientated vertically are applicable for elements used in an upright orientation. For horizontally oriented specimens, the results can be used in both horizontal or vertical alignments.

The rate of char is determined by the depth of char divided by the duration of the test. Char depth can be determined by identifying the 300°C isotherm.

Calculation Method

The calculation method under fire load uses the same assumption as for Stability and strength conducted for the ambient temperature, i.e. cold conditions, except for the following minor changes as summarised:

- Design for strength in the ultimate limit state (ULS).
- Use the reduced load combinations specified by AS 1170.0, Section 4.2.4.

  $G + \psi_l Q$ and any action arising from thermal effects.

  ψ_l for Residential, offices, parking and retail $\psi_l = 0.4$. For storage and other $\psi_l = 0.6$.
- *k* factors as per standard structural design, but the load of duration shall be taken as 5 hours.
- Effective length of the element must consider any reduction of constraint that might occur due to fire exposure.
- ϕ factor as per standard structural design.
- The deflection should be calculated from the effective residual section and that the deflection limits are the responsibility of the design engineer; however, consideration is required to ensure that the deflection does not cause an opening, causing an integrity failure or affect other elements relying on the timber structure for support, such as concrete slab in timber concrete composite design.

1.4.4 Determining the Insulation

AS/NZS 1720.4 provides two methods to determine the insulation capacity of a timber element. The first method is by a test to AS 1530.4, and the procedures of determining Insulation are found in this Standard. Alternatively, AS/NZS 1720.4 provides the minimum thickness of residual timber of 23 mm when the effective depth of char is determined by calculation. This method provided a minimum of 30 mm thick timber.

1.4.5 Determining the Integrity

There is only one method to determine Integrity, and that is by standard fire test to AS 1530.4.

2

Fire Safety of Timber Concrete Composite (TCC) Floors

Timber concrete composite floors are where the timber and concrete work together to act as a floor system. Generally, the timber is connected to the concrete with shear connectors. This can reduce the amount of concrete required, as well as increasing the spanning capacity of the timber. *WoodSolutions Technical Design Guide #30 Timber Concrete Composite Floors* provides a detailed design procedure for this floor system.

2.1 Criteria for Fire Resistance of TCC

The following discusses how fire resistance can be achieved for a timber concrete composite floor system. There are several approaches that can be used to be NCC compliant. The first method is to develop compliance from the timber only components. The second is to ignore the timber and just consider the concrete components. The third is to consider the timber and concrete contribution together. The following discusses the approach required to achieve the Fire Resistance Level's Structural, Insulation and Integrity values.

2.1.1 Design for Stability

Design for Stability requires that the floor must carry the applied loads for the full duration of the fire exposure, without collapse or excessive deformation. The applied load is much less than the standard structural load as specified in AS 1170 and discussed in Section 1.2.2.

The fire design must check whether the residual timber section, after the exposure period, will withstand the design load for the period of required fire resistance. This can be done by calculating the residual timber section by subtracting the effective char depth from all exposed sides of the element. The effective char can be calculated from AS/NZS 1720.4 and discussed in Section 1.4.3.

2.1.2 Design for Insulation

Design for Insulation requires that the temperature rise on the top surface of the floor acting as the fire-resisting barrier, i.e. not floor covering, must not exceed an average of 140°C at the end of the fire exposure. There are a number of approaches that can be used, and each is dependent on the makeup of the TCC floor and fire resistance period required.

The first approach is to consider timber providing all of the necessary Insulation, and this is suitable when permanent wood formwork is used. This approach uses the calculated insulation procedure from AS/NZS 1720.4 and Section 1.2.2. This method requires the timber providing the barrier to be at least the effective depth of char plus 23 mm for the fire resistance period required. If this is satisfied, it is DTS to the NCC BCA[2]. This method is suitable for low Fire Resistance Level periods.

An alternative method is to ignore the contribution of the timber and consider insulation being achieved just by the concrete. Insulation of concrete is achieved by minimum thickness of the concrete, and this thickness of concrete is different for each fire resistance level. The minimum thickness of concrete for the fire resistance levels can be found from the DTS Standard AS 3600 Concrete Structures. This Standard provides the minimum thickness of concrete for various fire resistance levels and is summarised in Table 2.1.

Table 2.1: Minimum thickness of the concrete to achieve various Fire Resistance Levels.

	Fire Resistance Level period (minutes)			
	30	**60**	**90**	**120**
Minimum thickness of the concrete (mm)	60	80	100	120

The third method can be used when there is permanent wood formwork below the concrete. In this situation, both the concrete and timber working together to provide the Insulation. The method is not DTS and will require the development of a performance solution.

The presumption is that the timber in the permanent formwork will take time to char through. This time can be calculated from AS/NZS 1720.4 and Section 1.4.3. The time to char through the permanent formwork can reduce the fire resistance period required for the concrete. This provides for a new fire resistance period for the concrete and the minimum thickness of concrete required can be determined from Table 2.1.

Example: If a TCC floor were used for a residential apartment, it would require 90 minutes of fire resistance. If the TCC floor had 25 mm pine plywood is used as permanent formwork, then for the National Char rate of pine from AS/NZS 1720.4 of 0.65 mm/minute, the plywood would provide 38 minutes, i.e. 25/0.65.

Now the Fire Resistance Level of 90 can be reduced by 38 minutes to 52 minutes fire resistance required by the concrete. From Table 2.1 above, the minimum thickness of concrete for 52 minute fire resistance is 80 mm, a reduction of 20 mm that would be required for 90 minutes of fire resistance.

2.1.3 Design for Integrity

Design for Integrity requires that there must be no gaps or openings that allow the transmission of flames or hot gases through the floor for the fire exposure period. In achieving Integrity, it is dependent on the pathway that has been chosen for compliance. As discussed above, there are three methods, through the timber, the concrete or a combination of both.

For timber, compliance can only be achieved if the joint between panels and other elements is based on a standard fire test, as AS/NZS 1702.4 only has a test to AS 1530.4. For an LVL based system, there is an assessment by Warringtonfire[3] for a number of common methods to join LVL panels together for a variety of FRLs, refer to Figure 2.1.

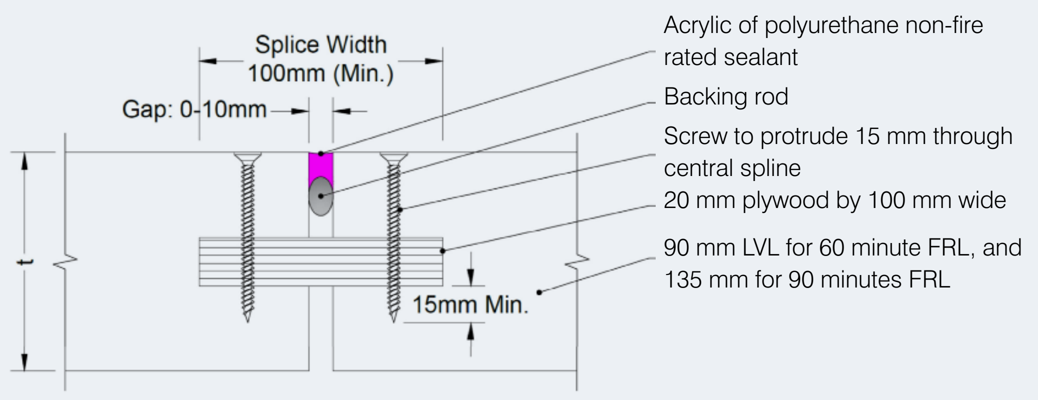

Figure 2.1: Compliant Integrity Joint in LVL Panels.

For concrete, Integrity can be achieved by having the minimum thickness of concrete for the fire-resistant period specified in Table 2.1.

The third method can be used when there is permanent wood formwork below the concrete. In this situation, both the concrete and timber working together to provide the Insulation. The method is not DTS and will require the development of a performance solution.

2.1.4 Shear Connector Fire Resistance

Protection of the shear connector in a TCC floor system can be achieved when the metal connector is fully embedded in the timber and concrete. For timber, the metal connector needs to be at least the minimum depth of effective char calculated for that fire resistance period. Shear connectors are usually provided by placement at the centre of the top edge of the timber joists.

2.2 Fire Design

The following checks the fire resistance capacity of a 400 × 63 mm LVL joist used for a TTC floor for FRL of 90 minutes, using AS/NZS 1720.4 calculation method.

Calculate Notional Charring Rate (C in mm/min):

$$C = 0.4 + (280/D)^2 \quad (2.1)$$

where

D = timber density at a moisture content of 12% in kg/m^3

In this example, radiata pine LVL that has a species density of 550 kg/m^3 density is used.

$\therefore C = 0.4 + (280/550)^2 = 0.66$ mm/min

Effective Depth of Charring (mm):

$$d_c = C.t + 7.0 \quad (2.2)$$

where

C = notional charring rate in mm/min, calculated above

t = period of time for the fire resistance required i.e. FRL, in minutes 90 mins

$\therefore d_c = 0.66 \times 90 + 7.0$ mm= 66.3 mm

This calculates the char protection, but the joist needs to include residual timber section to carry tension and bending, i.e. 67 + 67 + some wood to act in tension.

The char layer has to be applied to all exposed surface; generally, for a beam, this is for three sides, i.e. the two sides and bottom of the beam (see Figure 2.2), while a column requires the char layer applied to all sides. Generally, more economical timber section sizes are found by reducing the exposed surfaces of the timber element.

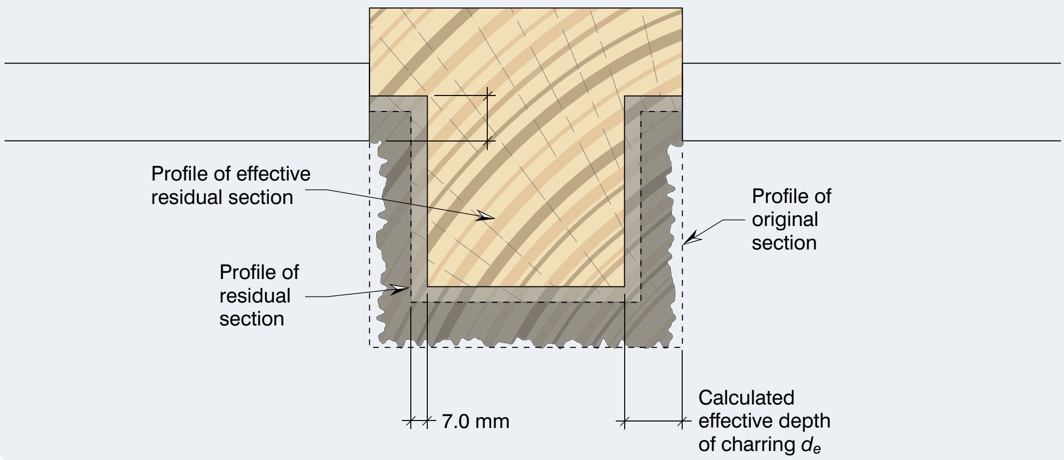

Figure 2.2: Char to timber beam on three sides.

The designer must also check whether the residual timber section will withstand the design load for the period of required fire resistance. Use the reduced load combinations as specified by AS 1170.0, Section 4.2.4 as G + ψ_l Q and any action arising from thermal effects. As the minimum requirement, the deflection should be less to span/30.

2.3 Construction using Double Joists

If the timber joists used for the TCC floors are made from two or more elements laminated together, special precautions must be taken to ensure that the individual elements do not separate during fire exposure. A gap may form between the laminated joists due to shrinkage effects that may expose the internal surfaces of the joist, increasing the number of surfaces that char can occur.

Prevention of this separation can be achieved by factory-gluing the joists or by using screws.

Where an adhesive is used, and the calculation method to determine the AS/NZS 1720.4 effective depth of char is required, only adhesives that are phenol, resorcinol, phenol-resorcinol or poly-phenolic can be used. Where an alternative method to arrive at fire resistance is used, such as a fire resistance ceiling, then the adhesive requirement can be ignored.

Where screws are used, they must be threaded over their full length. Screw spacing should be at 200 mm centres along the joists, preferably staggered in height. For joists greater in-depth than 400 mm, the second row of screws is required. The bottom row of screws must be far enough from the bottom edge of the joist, at least AS/NZS 1720.4 effective depth of char, to avoid charring of the wood reaching the screws during the fire exposure, as shown in Figure 2.3. The screw length must provide for at least 40 mm of penetration into the second joist.

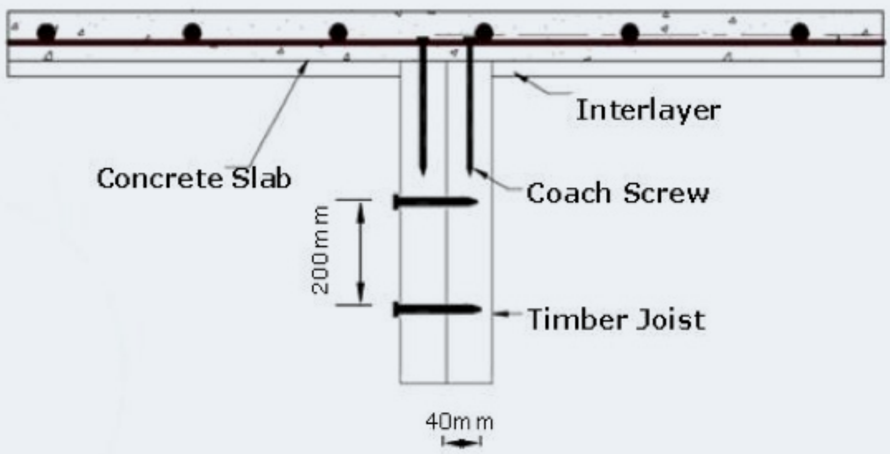

Figure 2.3: Screw arrangement for laminated joists.

2.4 Other Factors

The designer of the floor system must check the fire resistance of any horizontal or vertical penetrations made through the floor. Furthermore, consideration is requirements for surface spread of flame, on exposed wood ceilings. The NCC BCA[2] has specific limits on fire hazard of ceiling linings (Group Number), and limits materials due to the location within the building, occupancy or use and whether sprinklers are installed. It may be necessary to install sprinklers, limit the area of exposed wood surfaces or conduct a Performance Solution, to allow the use of an exposed ceiling in some building type sand locations. *Wood Solutions Technical Design Guide #19: Alternative Solution Fire Compliance, Internal Linings* steps through the process of a Performance Solution for coverings.

2.5 Verification by Test

A part of the Structural Timber Innovation Company research program, full-scale fire resistance tests were conducted at the Building Research Association of New Zealand (BRANZ)[4] laboratories on Timber Concrete composite floors.

3

Fire Safety of Timber Cassette Floors

Timber cassette floors are where the entire floor is made from timber. They consist of a timber joist (LVL or glulam) sandwiched between two timber sheathing layers. The sheathing is rigidly connected to the beams by a combination of adhesives and mechanical fasteners to ensure composite action. *WoodSolutions Technical Design Guide #31 Timber Cassette Floors* provides a detail design procedure for this floor system.

3.1 Design for Stability - Timber Cassette Floors

In the case of exposed sections, the same principle of char providing the fire resistance as described in Section 1.4 is used. Calculsations and design process for structural Stability are given below for the floor, without any fire-rated ceiling or additional protection. The calculations are based on AS/NZS 1720.4.

Alternatively, a protective layer of timber can be used, and the thickness must be greater than the effective depth of char calculated from AS/NZS 1720.4. There is no prescriptive guidance on the fixing of the timber coverings to the element, so this must be undertaken as a performance solution.

3.1.1 Design Example – Stability

The calculation method is same as for cold conditions, with minor changes as summarised below:

- Design for strength in the ultimate limit state (ULS).
- Use the reduced load combinations specified by AS 1170.0, Section 4.2.4, i.e. $G + \psi_l Q$ and any action arising from thermal effects. Note ψ_l for Residential, offices parking and retail $\psi_l = 0.4$, and for storage and other $\psi_l = 0.6$
- AS/NZS 1720.4 notes that deflection should be calculated from the effective residual section and that the deflection limits are the responsibility of the design engineer; however, consideration is required to ensure that deflection does not cause an opening to occur, leading to an integrity failure.
- *k* factors as per standard structural design but the load of duration shall be taken as 5 hours.
- ϕ factor as per standard structural design AS 1720.1.

Fire design example:

What width of a 400 mm deep LVL joist is required to provide 90 minutes fire resistance?

Assume 35 mm is required to support cassette post-fire.

Step One: Calculate the Notional Charring Rate (C in mm/min):

$$C = 0.4 + (280/D)^2 \quad (3.1)$$

where

D = timber density at a moisture content of 12% (kg/m^3)

Use 550 kg/m^3 density, a common average density for LVL with a base timber species of radiata pine.

$\therefore C = 0.4 + (280/550)^2 = 0.66$ mm/min

Step Two: Calculate the effective depth of char to give 90 minutes of fire resistance:

Effective Depth of Charring (mm):

$$dc = C.t + 7.0 \quad (3.2)$$

where

C = notional charring rate in mm/min, calculated above

t = period of time for the fire resistance required, i.e. FRL, in minutes 90 mins

$\therefore dc = 0.66 \times 90 + 7.0$ mm $= 66.3$ mm

The above calculates the char protection, but it needs to include residual timber section to carry tension and bending, assumed before of 35 mm, i.e. 67 + 67 + 35 = 169 mm (see Figure 3.1).

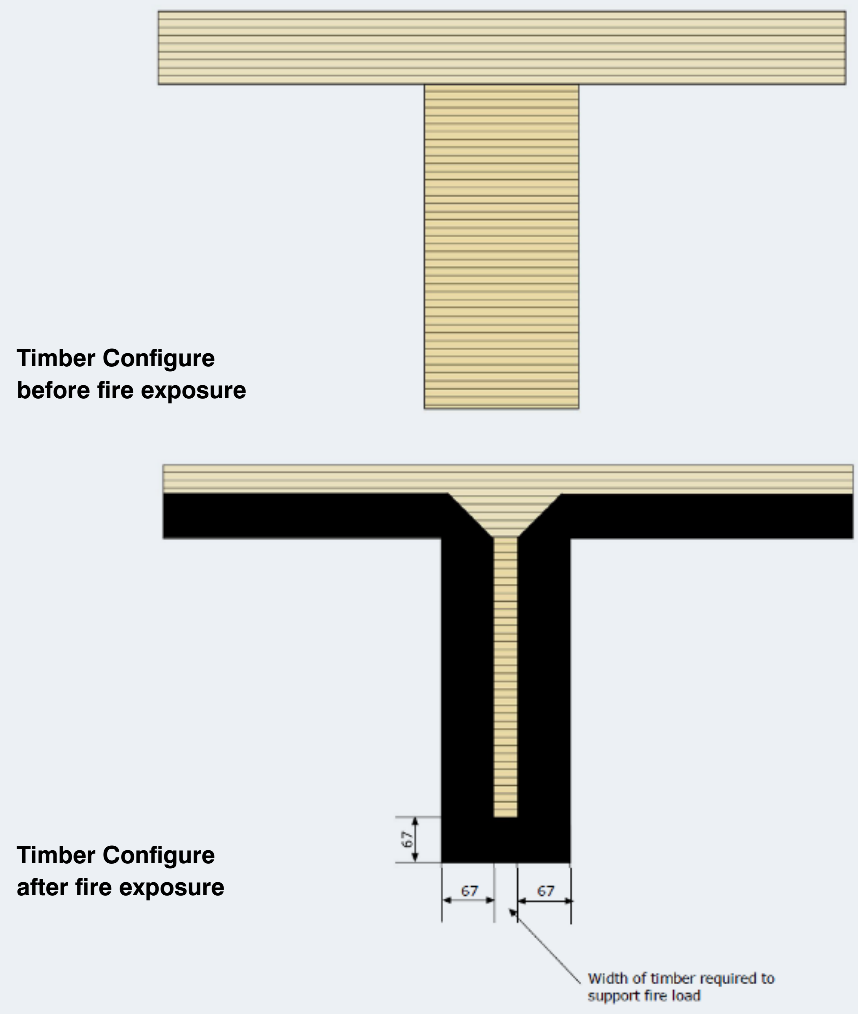

Figure 3.1: Comparison of Timber Cassette floor joists and Residual Section after 90 minutes of fire exposure.

Step Three: Determine the size of Joist

The designer must be mindful of the available timber sizes, as non-standard sizes are not readily available or are expensive. Commonly available LVL widths include 35 mm, 45 mm, 63 mm and 75 mm with depths from 90 mm to 450 mm. Therefore, the design selects the combination of standard LVL widths to make up a size greater than 169 mm.

For example: 63 + 45 + 63 = 171 > 169 mm

3.2 Design for Insulation - Timber Cassette Floors

For an all timber system, the only prescriptive method is to use the calculated insulation procedure from AS/NZS 1720.4, refer to Section 1.2.2. This method requires the timber providing the barrier to be as thick so that after the charring has occurred due to the fire exposure, plus the zero strength layer – 7.0 mm, there remains 23 mm.

Insulation panel thickness = Effective depth of char (including zero strength layer) + 23 mm (3.3)

3.2.1 Design Example – Insulation

AS/NZS 1720.4 requires the effective depth of char plus 23 mm will give the thickness of the floor panel required to provide Insulation for the fire exposure. Form the above design example, the effective depth of char was found in Section 3.1.1, being 67 mm for 90 minutes of fire resistance. Therefore Insulation can be met by adding 23 mm, i.e. 67 + 23 = 90 mm thick LVL floor panel (see Figure 3.4).

The above calculates the char protection, but it needs to include residual timber section to carry tension and bending, assumed before of 35 mm, i.e. 67 + 67 + 35 = 169 mm (see Figure 3.1).

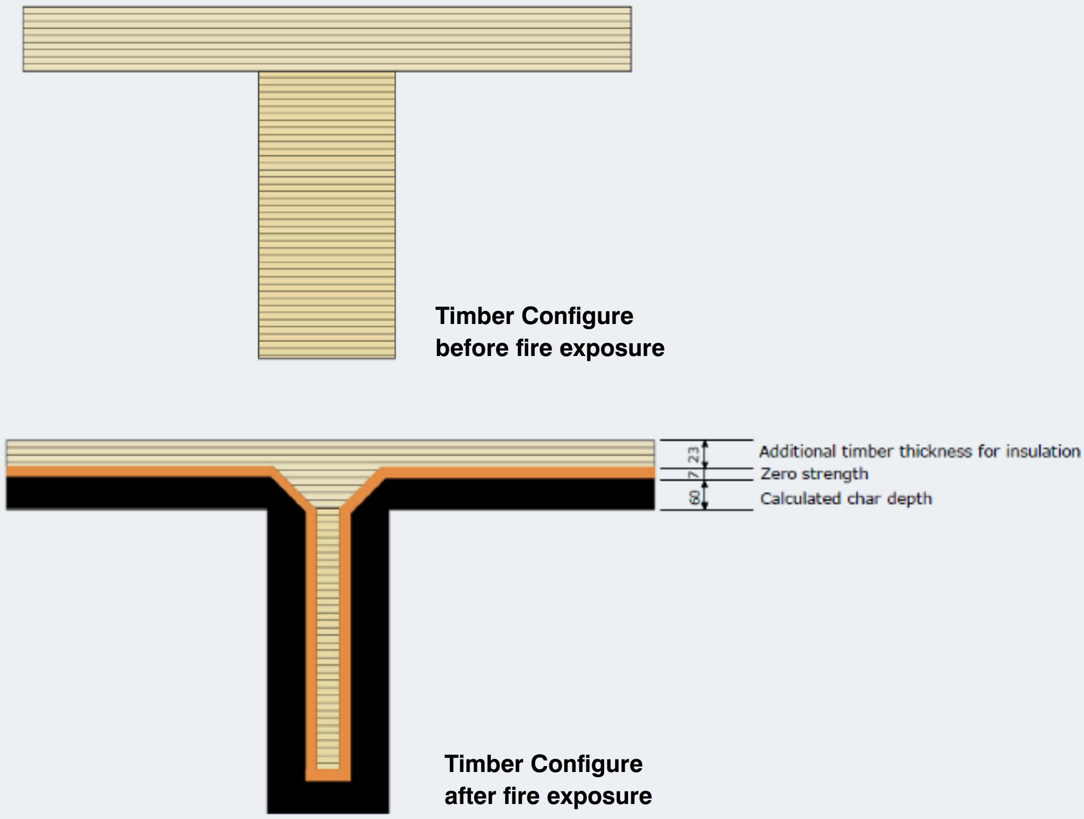

Figure 3.4: Insulation provided by the minimum thickness of the floor panel.

3.3 Other Factors

The designer of the floor system must check the fire resistance of any horizontal or vertical penetrations made through the floor. Also consider surface spread of flame on exposed wood ceilings. The NCC BCA[2] has specific limits on fire hazard of ceiling linings (Group Number), and limits materials due to the location within the building, occupancy or use and whether sprinklers are installed. It may be necessary to install sprinklers, limit the area of exposed wood surfaces or conduct a Performance Solution to allow the use of an exposed ceiling in some building types and locations. *Wood Solutions Technical Design Guide #19: Alternative Solution Fire Compliance, Internal Linings* steps through the process of a Performance solution for coverings.

3.4 Verification by Test

A part of the Structural Timber Innovation Company research program full-scale fire resistance tests was conducted at the Building Research Association of New Zealand (BRANZ)[4] laboratories on Timber Concrete composite floors.

4

Fire Safety of Post-Tensioned Timber Frames

The Post-Tensioned Timber Frames technology uses unbonded steel tendons in ducts in large timber box beams, frames or walls. It creates moment-resisting timber frames, the horizontal steel tendons also pass through the columns, providing moment resistance. In walls, the vertical tendons are anchored to the foundations. The system can also be used with draped tendons in long-span beams over a number of internal supports or with vertical post-tensioning in columns or solid timber shear walls with vertical ducts for the tendons.

Figure 4.1: Post tension Frame Massey University, Wellington, New Zealand. (Image credit: STIC)

4.1 Two Fire Safety Approaches for Post-Tensioning

There are two alternativess for fire design in post-tensioned buildings (see Table 4.1). A decision on which approach to use must be made early in the design process.

Option 1: Protect the post-tensioning

The first option is to protect all the steel components used in the post-tensioning system, i.e. tendons, anchorages, etc. This protection will prevent the temperature of the steel components increasing significantly for the duration of the required fire resistance time. Thus, structural fire safety design can incorporate the contribution of post-tensioning. The timber members must be sized to ensure there is sufficient residual timber to resist the applied loads and the post-tensioning forces for the duration of the fire.

Option 2: No post-tensioning for fire design

The second option relies solely on the residual timber members to resist the applied loads during a fire, so the steel post-tensioning components do not need to be protected. The members must be large enough for the residual timber section to resist the reduced loads in fire conditions. The residual section size is easily calculated by reducing the total section size by the char depth on surfaces exposed to fire.

This option requires careful consideration of the lateral load resistance of the whole building after the fire. This is especially important if the post-tensioning is an integral component of a lateral load resisting frame. For a multi-storey building, the fire will be contained within a single fire compartment at a single floor level, so the residual lateral load-resisting capacity of the structure on the floors unaffected by fire should be able to provide sufficient residual lateral load resistance for the whole building, but this needs to be checked carefully.

Table 4.1: Advantages and disadvantages of each option.

Option post-tensioning	Advantages	Disadvantages
1. Fire-protect all	• No reduction in post-tensioning during a fire • Full lateral-load resistance • during fire	• Specific detailing required • The additional cost to protect the post-tensioning
2. No fire protection of post-tensioning	• No additional design steps for fire design • Faster construction • Reduced cost of protection	• Does not utilise existing • Post-tensioning capacity

Figure 4.2 shows a fire resistance test of a post-tensioned timber beam, during unloading after 60 minutes of fire exposure. Also visible in the photograph are several post-tensioning anchorages that were tested at the same time.[5]

Figure 4.2: Fire resistance test of a post-tensioned timber beam.[5]

4.2 Fire Design of Post-Tensioning, Brackets, Corbels and Dissipaters

Steel is a highly conductive material so any exposed steel components are sensitive to increases in temperature; this is particularly true for exposed steel used in the post-tensioning.

The yield strength of steel is significantly reduced when it exceeds a temperature of about 500°C, so the load-carrying capacity of a post-tensioning system is negligible if the tendons are exposed to fire. Steel tendons inside timber box members will not lose much strength in a fire because they are protected from elevated temperatures by the thermal insulating properties of the timber. The post-tensioning anchorages may need fire protection if they are within the building and likely to be exposed to fire.

4.2.1 Fire Resistance of Post-Tensioning

The design of fire resistance for post-tensioning will depend on the selected strategy. If the post-tensioning requires fire resistance, this must include:

- protection of tendons
- protection of anchorages.

Services or other structural elements, i.e. post-tensioned steel tendons, may be installed in this cavity and serve a particular function. The cavity temperature and the behaviour of these elements must be known to provide adequate information for the fire performance of the floor assembly as a whole.

For example, a post-tensioned steel tendon may be installed in the cavity to aid in resisting loads imposed on the floors, and increases in temperature can result in losses of tensioning force, which can have disastrous effects on these types of systems, as investigated by Spellman et al.[6]

If the tendons are hidden from view in a cavity within the beam or the wall, it is unlikely that additional fire protection is necessary because of the excellent insulating properties of the residual wood below the char layer (see Figure 4.3). However, simple calculations may be necessary to determine the maximum temperature reached inside the cavity.

Figure 4.3: Inside a cavity carrying post-tensioning rods, post-fire.[6]

The cavity surface temperature, and therefore the tendon temperature, can be estimated using an assumed temperature distribution for the timber underneath the char layer. Buchanan1 presents the following parabolic distribution:

$$T(x) = T_{\text{i}} + (T_{\text{p}} - T_{\text{i}})(1 - \frac{x}{a_{\text{heated}}})^2 \quad (4.1)$$

where

$T(x)$ is the temperature of the timber at a distance beneath the char layer.

T_i is the initial or ambient temperature of the timber. Default 20°C.

T_p is the charring or pyrolysis temperature of the timber. Default 300°C.

a_{heated} is the thickness of the heat-affected layer. Default 40 mm.

This relationship is only valid for values of x between zero and a_{heated}. For a greater distance, the temperature should be taken as Ti. The value x can also be used as the remaining thickness of the timber. This will return an approximate value for the temperature on the internal surface of the timber cavity. If the thickness of the webs and flanges are different, use the thickness of the thinnest component, which will give a more conservative estimate.

If the post-tensioning is required to be protected from fire, it is essential to ensure that the anchorages also have the same fire resistance. In many cases, these anchorages will be protected by other structures or be outside the building envelope, but in other cases, it will be necessary to apply fire protection to the anchorage using protective material or intumescent paint. Some guidance is given by Spellman.[5] Early discussion with the fire engineer is essential to determine the most appropriate protection requirements corresponding to the fire design strategy for the building.

(a) Anchorages, corbels and dissipaters with no fire protection. Merritt building.

(b) Wall anchorages and UFPs with no fire protection. NMIT building.

Figure 4.4: Some fire-related details in other buildings.

4.2.2 Fire Resistance of Brackets and Corbels

The fire engineer must assess whether exposed steel brackets, joist hangers or corbels require fire resistance, depending on the fire safety strategy. If fire resistance is required, it can usually be provided by protective material or intumescent paint. A corbel protected with intumescent paint is shown in Figure 4.5b.

(a) Exposed tendons, no fire resistance.

(b) Steel corbel protected with intumescent paint.

Figure 4.5: Fire protection details at Massey Building, Wellington, New Zealand.

4.2.3 Fire Resistance of Dissipaters

External dissipaters that are part of the structural system will not normally need to be protected from fire, as shown in Figure 4.3a. If the dissipaters are contributing to the gravity load resistance during normal building operation, then special consideration will need to be given to the dissipaters to determine whether protection is required under reduced fire loading conditions.

4.2.4 Fire Protection of Service Holes

Any service holes through fire-resisting floors or walls must be detailed to prevent fire passing through the assembly, in order to retain at least the same fire resistance as the penetrated element. The effect of charring must be calculated for all exposed surfaces, including those at service holes.

4.3 Fire Design Example of Post-Tensioned Timber Frames

An LVL post-tension timber frame is checked In the following design example.

4.3.1 Design for Stability

The principle of char calculation described in Section 1.4 is used. The calculations are based on AS/NZS 1720.4. A protective layer of timber can be used and can be calculated from AS/NZS 1720.4.

4.3.1.1 Calculation Method

The calculation method is same as for cold conditions, with the following minor changes:

- Design for strength in the ultimate limit state (ULS).
- Use the reduced load combinations specified by AS 1170.0, Section 4.2.4. G + ψ_lQ and any action arising from thermal effects.
- ψ_l for residential, offices, parking and retail $\psi_l = 0.4$. For storage and other $\psi_l = 0.6$.
- AS/NZS 1720.4 notes that deflection should be calculated from the effective residual section and that the deflection limits are the responsibility of the design engineer; however, consideration is required to ensure that there is no failure in the concrete slab or that the deflection does not cause an opening, causing an integrity failure.
- *k* factors as per standard structural design but the load of duration is taken as 5 hours.
  - *k* factors ($k_1 = 1.0$, $k_4 = 1.0$, $k_6 = 1.0$, $k_9 = 1.0$, $k_{12} = 1.0$)
- ϕ factor as per standard structural design.
  - ϕ factor $= 1.0$

Design Example

Three cases are considered:

- Case 1 considers a simply supported, post-tensioned beam with a straight tendon.
- Case 2 considers a simply supported, post-tensioned beam with a draped tendon.
- Case 3 considers a post-tensioned beam in a frame with a draped tendon.

A design example with calculations is provided for Case 1. Two calculation processes are detailed in Case 1 to consider beams with protected and unprotected post-tensioning systems separately. Detailed design calculations are not provided for Cases 2 and 3; however, the additional considerations needed for the design of a beam with draped tendons or a beam within a frame are discussed. Cross-section of a simply supported post-tensioned beam is shown in Figure 4.4.

The following factors and properties are used in the design example.

- ϕ factor $= 1.0$
- *k* factors ($k_1 = 1.0$, $k_4 = 1.0$, $k_6 = 1.0$, $k_9 = 1.0$, $k_{12} = 1.0$)
- Characteristic stress values
  - $f_b = 48.0$ MPa
  - $f_s = 6.0$ MPa
  - $f_c = 45.0$ MPa

Case 1: Simply Supported, Post-Tensioned Beam with Straight Tendon

Figure 4.6 illustrates the configuration of the Post-Tension beam.

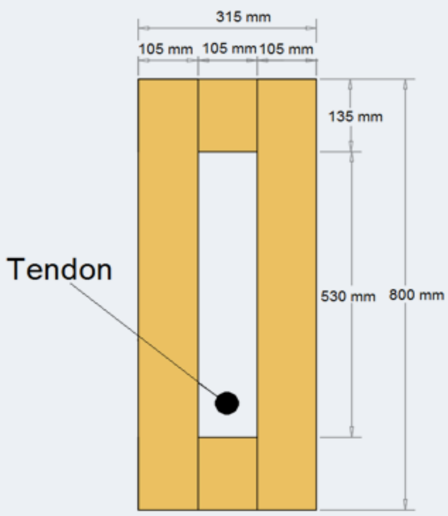

Figure 4.6: Cross-section of a simply supported post-tensioned beam.

The first stage of the fire design is to decide whether the post-tensioning system will be protected from exposure to fire. Calculations detailing the strength checks for beams using both unprotected and protected post-tensioning systems are shown below.

Calculation 1: Unprotected Post-Tensioning System

The FRL will first be checked for a beam where the post-tensioning system is unprotected. Therefore, the post-tensioning system will not contribute to the strength of the beam.

New section properties must be calculated for the residual beam section remaining after the expected duration of fire exposure.

Calculate notional Charring Rate (C in mm/min):

$$C = 0.4 + (280/D)^2 \qquad (4.2)$$

where

D = timber density at a moisture content of 12% (kg/m^3).

Use 550 kg/m^3 density as this is a common average density for LVL with a base timber species of radiate pine.

$\therefore C = 0.4 + (280/550)^2 = 0.66$ mm/min

Effective Depth of Charring (mm):

$$d_c = C.t + 7.0 \qquad (4.3)$$

where

C = notional charring rate in mm/min, calculated above.

t = period of time for the fire resistance required i.e. FRL, in minutes 90 mins.

$\therefore d_c = 0.66 \times 90 + 7.0$ mm $= 66.4$ mm

The char depth after 90 minutes fire exposure is: 67 mm.

Considering the three-sided exposure of the beam, with the top surface concealed from fire by the floor, only the bottom and side thicknesses are reduced by this depth. It is assumed corner rounding has a negligible effect on the performance of the beam so this has not been considered in these calculations. The residual section, with the original section shown by the dashed line, is shown in Figure 4.7.

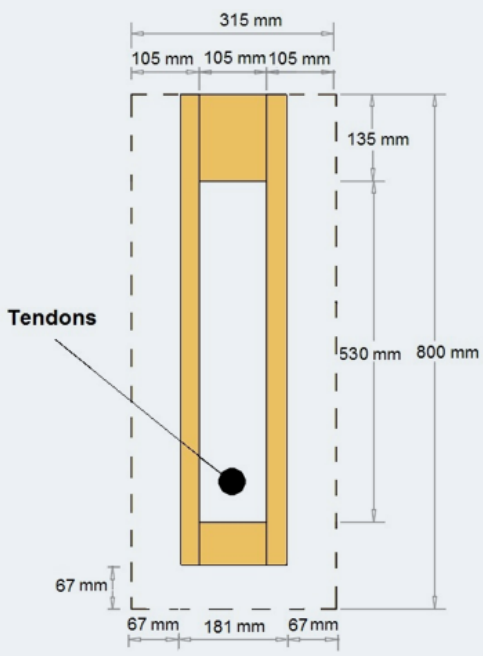

Figure 4.7: Residual cross-section of a simply-supported post-tensioned beam.

The residual section properties are then calculated as:

c =neutral axis depth from bottom=392.3 mm

$A = 77.02 \times 10^3$ mm^2

$Z = 11.60 \times 10^6$ mm^3

$Q_{centroid} = 8.35 \times 106$ mm^3

$I = 4.53 \times 10^9$ mm^4

where

c = neutral axis depth

A = area of timber member

Z = section modulus of timber member

$Q_{centroid}$ = first moment of area of timber member

The external load on the beam is calculated as G + ψ_lQ where the coefficient for the fire case is the same as was calculated for SLS 2, with ψ_l of 0.4. These loads, obtained from previous sections, are:

$$G = 3.7\frac{\text{kN}}{\text{m}^2} \times 8.0 \text{ m} = 29.6 \frac{\text{kN}}{\text{m}} \tag{4.5}$$

$$\psi_l Q = 0.4 \times 3.0 \frac{\text{kN}}{\text{m}^2} \times 8.0 \text{ m} = 9.6 \frac{\text{kN}}{\text{m}} \tag{4.6}$$

The uniformly distributed load is:

$$q = G + \psi_l Q = 29.6 + 9.6 = 39.2 \frac{\text{kN}}{\text{m}} \tag{4.7}$$

From this the maximum demands were calculated as:

$$M^* = \frac{qL^2_B}{8} = \frac{39.2 \times 8.6^2}{8} = 362 \text{ kNm} \tag{4.8}$$

$$V^* = \frac{qL_B}{2} = \frac{39.2 \times 8.6^2}{2} = 169 \text{ kNm} \tag{4.9}$$

As the beam chars, the neutral axis of the section changes as the beam is no longer symmetrical about all axes.

The bending strength of the section is:

$$f'_b = f_b \times \left(\frac{300}{h_b}\right)^{0.167} = 48.0 \times \left(\frac{300}{733}\right)^{0.167} = 41.35 \text{ MPa} \tag{4.10}$$

$$M_d = \emptyset k_1 k_4 k_6 k_9 k_{12} f'_b Z$$
$$= 1.0 \times 1.0 \times 1.0 \times 1.0 \times 1.0 \times 1.0 \times 41.35 \times 11.60 = 479.7 \text{ kNm} \tag{4.11}$$

Checking the bending:

$$M_d \geq M^* \tag{4.12}$$

$480.6 \geq 362 \rightarrow \text{OK}$

The shear strength of the section is:

$$A_s = 2t_w \times \frac{I}{Q_{centroid}} = 2 \times 38 \times \frac{4.53 \times 10^9}{8.35 \times 10^6} = 41.2 \ \times 10^3 \ \text{mm}^2 \tag{4.13}$$

$$V_d = \phi k_1 k_4 k_6 f_S^{'} A_s = 1.0 \times 1.0 \times 1.0 \times 1.0 \times 6.0 \times 41.2 \times 10^3 = 247.2 \ \text{kN} \tag{4.14}$$

Checking the shear:

$$V_d \geq V^* \tag{4.15}$$

247.2 kN ≥ 169 kN → OK

For small residual sections, the maximum stresses in the tension and compression zones should be checked. Crushing failures may occur in the top flange, and failure may also occur when the bottom flange becomes too thin to carry the maximum tensile stresses. The Eurocode 5[7] design checks for tension and compression will be completed.

The mean compressive stress in the top flange is calculated to be:

$$\sigma_{f,c,d} = \frac{M^* \times (c - \frac{t_{f,c}}{2})}{I} = \frac{362.0 \times 10^6 \times (342.3 - \frac{135}{2})}{4.53 \times 10^9} = 22.0 \ \text{MPa} \tag{4.16}$$

The compression capacity parallel to grain is:

$$f_c^{'} = f_c \times (\frac{95}{h_b})^{0.167} = 45.0 \times (\frac{95}{733})^{0.167} = 32.0 \ \text{MPa} \tag{4.17}$$

$$\therefore \ k_c f_{c,0,d} = k_c \phi k_1 k_4 k_6 f_c^{'} = 1.0 \times 1.0 \times 1.0 \times 1.0 \times 1.0 \times 32.0 = 32.0 \ \text{MPa} \tag{4.18}$$

Checking the compression capacity against the mean compressive stress:

$$\sigma_{f,c,d} \leq k_c f_{c,0,d} \tag{4.19}$$

22.0 MPa ≤ 32.0 MPa → OK

The mean tensile stress in the bottom flange is:

$$\sigma_{f,t,d} = \frac{M^* \times (h_b - c - \frac{t_{f,t}}{2})}{I} = \frac{362.0 \times 10^6 \times (733.0 - 390.7 - \frac{68}{2})}{4.53 \times 10^9} = 24.6 \ \text{MPa} \tag{4.20}$$

The tension capacity parallel to grain is:

$$f_t^{'} = f_t \times (\frac{150}{h_b})^{0.167} = 30 \times (\frac{150}{733})^{0.167} = 23.0 \ \text{MPa} \tag{4.21}$$

$$f_{t,0,d} = \phi k_1 k_4 k_6 f_{t\backslash}^{'} = 1.0 \times 1.0 \times 1.0 \times 1.0 \times 23.0 = 23.0 \ \text{MPa} \tag{4.22}$$

Checking the tension capacity against the mean tensile stress:

$$\sigma_{f,t,d} \leq f_{t,0,d} \tag{4.23}$$

24.6 MPa ≈ 23.0 MPa → OK

All strength checks are OK. Hence the beam can withstand 90 minutes of fire exposure without failure.

Calculation 2: Protected Post-tensioned System

If the post-tensioning system is fire protected, including all anchorages, the post-tensioning system can be considered in the strength calculations of the beam as shown below.

Second-order effects, including beam end rotations and bowing due to axial forces acting on the deflected member, have a minimal impact on the design and so have not been considered. Also, tendon relaxation due to heating has been ignored as it is assumed the post-tensioning system remains at ambient temperature as it is fully protected from fire exposure, but tendons relaxation overall will need to be included.

The residual section dimensions and properties after 90 minutes of fire exposure are the same as Calculation 1:

c = neutral axis depth from bottom = 390.7 mm

$A = 77.02 \times 10^3$ mm^2

$Z = 11.60 \times 10^6$ mm^3

$Q_{centroid} = 8.35 \times 10^6$ mm^3

$I = 4.53 \times 10^9$ mm^4

The external loads are the same as per Calculation 1. However, the axial compression force caused by the post-tensioning must also be considered. Again SLS2, with ψ_{tl} of 0.85 to account for 15% losses in post-tensioning force, is considered:

$$G = 3.7\frac{\text{kN}}{\text{m}^2} \times 8.0\ \text{m} = 29.6\ \frac{\text{kN}}{\text{m}} \tag{4.24}$$

$$\psi_1 Q = 0.4 \times \frac{3.0\ \text{kN}}{\text{m}^2} \times 8.0\ \text{m} = 9.6\ \text{kN/m} \tag{4.25}$$

$$\psi_{tl}\,PT = 0.85 \times 1100\ \text{kN} = 935\ \text{kN} \tag{4.26}$$

The uniformly distributed load is:

$$q = G + \psi_l Q = 29.6 + 9.6 = 39.2\ \text{kN/m} \tag{4.27}$$

From this, the maximum demands were calculated as:

$$M^* = \frac{qL_B^2}{8} = \frac{39.2 \times 8.6^2}{8} = 362.0\ \text{kNm} \tag{4.28}$$

$$V^* = \frac{qL_B}{2} = \frac{39.2 \times 8.6}{2} = 169.0\ \text{kN} \tag{4.29}$$

$$N^* = \psi_{tl}PT = 935\ \text{kN} \tag{4.30}$$

As the beam chars, the neutral axis of the section changes as the beam is no longer symmetrical about all axes.

The eccentricity of the tendon will create a moment that needs to be considered in the flexural demand on the beam. The change in neutral axis depth, due to loss of cross-section, increases the eccentricity to the post-tensioning.

So the eccentricity is:

$$e = e_0 + \Delta\bar{y} - \delta \tag{4.31}$$

where

e = eccentricity between centroid and tendon of residual section

e_0 = initial eccentricity = 280 mm

$\Delta\bar{y}$ = distance of centroid of original section to centroid of residual section = 60 mm

δ = elastic deflection of residual section at mid-span due to reduced gravity loads ($\delta_{G+\psi_1 Q} = \frac{5ql^4}{384EI} = 56.7$ mm) minus the hogging deflection of the residual section at midspan due to post-tensioning system ($\delta_{\psi_{tl}PT} = \frac{e \cdot \psi_{t1} PT \cdot l^2}{8EI} = 54.0$ mm):

$$\delta = \delta_{G+\psi_1 Q} - \delta_{\psi_{t1}PT} = \frac{5ql^4}{384EI} - \frac{e \cdot \psi_{t1} PT \cdot l^2}{8EI} = 56.7 - 54.0 = 2.7 \text{ MM} \tag{4.32}$$

$\therefore$ e = 280+ 60 - (56.7 - 54.0) = 337.3 mm

Note that determining $\delta_{\psi_{tl}PT}$ equires an iterative calculation to be performed.

The post-tensioning moment is:

$$M_{PT} = e \times \psi_{lt} PT = 0.3373 \times 935 = 315.4 \text{ kNm} \tag{4.33}$$

So the new moment demand is:

$$M^* = M_q - M_{PT} = 362 - 315.4 = 46.6 \text{ kNm} \tag{4.34}$$

The bending strength of the section is:

$$f_b' = f_b \times \left(\frac{300}{h_b}\right)^{0.167} = 48.0 \times \left(\frac{300}{733}\right)^{0.167} = 41.3 \text{ MPa} \tag{4.35}$$

$$M_d = \phi k_1 k_4 k_6 k_9 k_{12} f_b' Z = 1.0 \times 1.0 \times 1.0 \times 1.0 \times 1.0 \times 1.0 \times 41.35 \times 11.6 = 479.7 \text{ kNm} \tag{4.36}$$

Checking the bending:

$$M_d \geq M^* \tag{4.37}$$

479.7 kNm ≥ 70 kNm → OK

The shear strength of the section is:

$$A_s = 2t_w \times \frac{I}{Q_{centroid}} = 2 \times 38 \times \frac{4.53 \times 10^9}{8.35 \times 10^6} = 41.2 \times 10^3 \text{ mm}^2 \tag{4.38}$$

$$V_d = \phi k_1 k_4 k_6 f_S' A_s = 1.0 \times 1.0 \times 1.0 \times 1.0 \times 6.0 \times 41.2 \times 10^3 = 247.2 \text{ kN} \tag{4.39}$$

Checking the shear:

$$V_d \geq V^* \tag{4.40}$$

247.2 kN ≥ 169 kN → OK

The compression strength of the section is:

$$N_d = \text{Ø} k_1 k_4 k_6 k_9 k_{12} f_c' A = 1.0 \times 1.0 \times 1.0 \times 1.0 \times 1.0 \times 45 \times 77.02 \times 10^3 = 3465.9 \text{ kN} \tag{4.41}$$

Checking the compression:

$$N_d \geq N^* \tag{4.42}$$

3476.3 ≥ 935 → OK

Now checking the combined action for bending and compression:

$$\frac{N^*}{N_\text{d}} + \frac{M^*}{M_\text{d}} \leq 1.0 \tag{4.43}$$

where

N^* = design compression force

N_d = design compression capacity

M^* = design bending moment

M_d = wind direction multiplier for the 8 cardinal directions

$$\frac{935}{3465.9} + \frac{70}{479.7} = 0.41 \leq 1.0 \rightarrow \text{OK}$$

Again for small residual sections, the maximum stresses in the tension and compression zones should be checked. This is of paramount importance with high levels of post-tensioning, as crushing failures may occur in the top flanges due to the extra-axial load imposed on the member. Failure may also occur when the bottom flanges become too thin to carry the maximum tensile stresses. The Eurocode 57 design checks for tension and compression will be completed.

The mean compressive stress in the top flange is calculated to be:

$$\sigma_{\text{f,c,d}} = \frac{M^* \cdot (c - t_{\text{f,c}}/2)}{I} + \frac{\Psi_{1t} PT}{A} = \frac{70 \times 10^6 \times (390.7 - 135/2)}{4.53 \times 10^9} + \frac{935 \times 10^3}{77.02 \times 10^3} \tag{4.44}$$

$= 20.1$ MPa (negative compression)

The compression capacity parallel to grain is:

$$k_\text{c} f_{\text{c,0,d}} = k_\text{c} \phi k_1 k_4 k_6 f_\text{c}' = 1.0 \times 1.0 \times 1.0 \times 1.0 \times 1.0 \times 32.0 = 32.0 \text{ MPa} \tag{4.45}$$

Now, checking the compression capacity against the mean compressive stress:

$$\sigma_{\text{f,c,d}} \leq k_\text{c} f_{\text{c,0,d}} \tag{4.46}$$

17.1 MPa ≤ 32.0 MPa → OK

The mean tensile stress in the bottom flange is:

$$\sigma_{f,c,d} = \frac{M^* . (c - t_{f,c}/2)}{I} + \frac{\Psi_{1t} PT}{A} = \frac{70 \times 10^6 \times (390.7 - 135/2)}{4.53 \times 10^9} + \frac{935 \times 10^3}{77.02 \times 10^3}$$

$$= 7.5 \text{ MPa (Positive Tension)} \tag{4.47}$$

The tension capacity parallel to grain is:

$$f_\text{t}' = f_\text{t} \times (\frac{150}{h_\text{b}})^{0.167} = 30 \times (\frac{150}{733})^{0.167} = 23.0 \text{ MPa} \tag{4.48}$$

Now apply factor

$$f_{\text{t,0,d}} = \phi k_1 k_4 k_6 f_\text{t}' = 1.0 \times 1.0 \times 1.0 \times 1.0 \times 23.0 = 23.0 \text{ MPa} \tag{4.49}$$

Now checking the tension capacity against the mean tensile stress:

$$\sigma_{\text{f,t,d}} \leq f_{\text{t,0,d}} \tag{4.50}$$

7.5 MPa ≤ 23.0 MPa → OK

All strength checks are okay. Hence the beam can withstand 90 minutes of fire exposure without failure.

Back calculations can be made to determine the actual fire resistance of the beam by deriving the section modulus or area required in each strength check and then substituting the charring equation into these. This gives a cubic formulation which, when solved, will give the expected fire resistance time of the member. The above equations can also be put into an excel spreadsheet, and a solver used to find the expected fire resistance.

Case 2: Simply Supported, Post-Tensioned Beam with Draped Tendon

The design of a beam with a draped tendon will follow a similar methodology as to that detailed above; the difference in the design of a beam with a draped tendon will arise when calculating the shear demand.

The draped tendon will result in a vertical component of the post-tensioning force. This will have the effect of decreasing the shear demand on the beam in the areas where the tendon is draped. As such, additional calculations can be completed to include the effect of the draped tendon profile, potentially producing a more efficient design. However, the effect of the draped tendon can be conservatively ignored and the calculations detailed for Case 1 can be followed.

The calculation to determine the eccentricity of the tendon will also change for a draped tendon. As the tendon is fixed in place by deviators, the tendon will deflect with the beam. Therefore the deflection component of the equation to calculate the eccentricity, $\boldsymbol{\delta}$, can be ignored, i.e.:

$$e = e_0 + \Delta\bar{y} \tag{4.51}$$

If the post-tensioning system is not protected there will be no difference in the design of a beam with a draped tendon compared to a straight tendon.

Case 3: Post-Tensioned Beam in a Frame with a Draped Tendon

It has been assumed in the calculations above that the beam is simply supported. As such, the negative moments at the ends of the beams, which would decrease the demand on the beam, are ignored. Therefore, if the beam is shown to be satisfactory for the simply supported case, it will also be satisfactory if the beam is part of a frame system. If the beam is not simply supported, additional calculations can be completed to include the effect of the frame system, which could produce a more efficient design.

4.4 Other Factors

The designer of the beam system must check the fire resistance of any horizontal or vertical penetrations through the beam.

Checks should be made on the size and residual bearing area of corbels and timber seatings, such that adequate bearing remains after a fire event.

The lateral Stability of the entire frame needs to be considered. If a fire event was to completely weaken or destroy a primary beam on one level of the structure, the entire structure should have enough remaining strength to withstand lateral actions.

If it is determined that the post-tensioning will be protected from fire exposure, the entire post-tensioning system, including the anchorages, must also be adequately protected to ensure the tendon is not heated during a fire.

4.5 Verification by Test

The design principles above have been checked by full-scale fire resistance tests at the laboratories of BRANZ (Building Research Association of New Zealand)[6], sponsored by the Structural Timber Innovation Company Ltd.

5

Construction Site Fire Safety

Construction site fire safety is important. Fires in timber buildings are infrequent, but the known examples in Canada, USA and UK have generally occurred in light timber-framed building and while the building is under construction. This is due to the light timber frame not having its protective covering applied until much later in the construction sequence. Massive timber construction is less susceptible than lightweight systems due to the char resistance large timber elements have.

WoodSolutions Technical Design Guide #20: *Fire Precautions During Construction of Large Buildings* provides information to help designers and organisations with responsibilities for fire safety on a construction site to reduce the risk of fire.

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WoodSolutions Technical Design Guides

Guide #3: *Timber-framed Construction for Commercial Buildings Class 5, 6, 9a & 9b*

Guide #17: *Alternative Solution Fire Compliance, Timber Structures.*

Guide #19: *Alternative Solution Fire Compliance, Internal Linings*

Guide #20: *Fire Precautions During Construction of Large Buildings*

Guide #30: *Timber Concrete Composite Floors*

Guide #31: *Timber Cassette Floors*

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AS 3600 *Concrete Structures*, 2009.

A

Appendix A – Notation

The symbols and letters used in the Guide are listed below:

a_{heated}	thickness of the heat-affected layer. Default 40 mm
A	area of timber member
A_s	shear area of member
c	neutral axis depth
C	notional charring rate in mm/min
D	timber density at a moisture content of 12% in kg/m^3
d_e	calculated effective depth of charring in mm
t	period of time, in minutes
e	eccentricity of post-tensioning
e_0	initial eccentricity of post-tensioning
f_b	bending strength
f'_b	design bending strength (including size factor)
f_c	compression strength of timber member parallel to grain
f'_c	characteristic compression strength parallel to grain
$f_{c,0,d}$	design compression strength parallel to grain (Eurocode 5)
f_s	shear strength of beam
f_t	tension strength of timber member parallel to grain
f'_t	design tension strength (including size factor)
$f_{t,0,d}$	design tension strength parallel to grain (Eurocode 5)
G	permanent action (dead load)
h_b	height of beam
I	moment of inertia for timber member
k_1	duration of load factor specified in AS 1720.1
k_4	partial seasoning factor specified in AS 1720.1
k_6	temperature factor specified in AS 1720.1
k_9	strength sharing between parallel members factor specified in AS 1720.1
k_{12}	stability factor specified in AS 1720.1
k_c	factor that takes into account lateral instability (Eurocode 5)
M_{pt}	bending moment due to post-tensioning
M_q	bending moment due to distributed load
M^*	design bending moment
M_d	wind direction multiplier for the 8 cardinal directions
N_d	design compression capacity
N	design compression force
PT	post-tensioning load

Q imposed action (live load)

$Q_{centroid}$ first moment of area of timber member

$t_{f,c}$ thickness of compressive flange

t_w thickness of web

$T(x)$ temperature of the timber at a distance beneath the char layer

T_i initial or ambient temperature of the timber; default 20°C

T_p charring or pyrolysis temperature of the timber; default 300°C

V^* design shear force

δ_d design shear capacity

$\delta_{G+\psi_1 Q}$ section modulus of timber member

$\delta_{\psi_{t1} PT}$ elastic deflection of residual section at mid-span

– elastic deflection of residual section at mid-span due to reduced gravity loads

δ elastic deflection of residual section at mid-span due to post-tensioning

Δy distance of centroid of original section to centroid of residual section

$\sigma_{f,c,d}$ mean flange design compressive stress (Eurocode 5)

$\sigma_{f,t,d}$ mean flange design tensile stress (Eurocode 5)

ϕ strength reduction factor

ψ_{tl} factor for tendon force under long-term SLS load

ψ_l combination factor for long-term imposed action

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Introduction

The next generation of timber buildings are being made from Massive Timber. They are mostly built from engineered timber elements that are generally 75 mm or greater in thickness from:

- Cross-laminated Timber – CLT
- Glue Laminated Timber – GLT or Glulam
- Laminated Veneer Lumber – LVL
- Nail Laminated Timber – NLT
- Dowel Laminated Timber – DLT

This guide discusses one of the Massive Timbers that is often used called Cross-laminated Timber (CLT). The guide's intention is to introduce CLT, providing general product and performance information, design consideration and building processes. The guide is not a design manual, for more detailed design information refer to producers or suppliers of CLT.

Figure 1: Cross-laminated Timber panel. *Photograph: Stora Enso*

Figure 2: Forté Living, Australia's first Cross-laminated Timber Building
Photograph: Lendlease

1

What is Cross-laminated Timber?

Cross-laminated timber (CLT) is a solid engineered wood product made of at least three orthogonally bonded layers of solid-sawn timber or engineered timber that are laminated by gluing of longitudinal and transverse layers with structural adhesives to form a solid rectangular-shaped, straight, and plane timber panel.

Dimensional seasoned timber is used; generally finger jointed to form long length boards. Low structural grades are most often used for the transverse layer and higher structural grades for the load direction. The panel can have three to seven layers or more (usually an odd number), which are symmetrical around the middle layer. While softwoods are most often used, it is feasible to manufacture CLT using hardwoods or engineered wood products such as LVL. In some instances, engineered wood products have been combined with CLT to form hybrid panels. These panels have improved air tightness, strength and screwing capacity.

Panel sizes vary by manufacturers, but typical widths are 0.6, 1.2 and 3.5 m; lengths can be up to 18 m. Thicknesses is dependent on the lamination thickness. Generally European CLT is made from 20, 30 or 40 mm lamination or a combination of both while Australian, New Zealand and North American laminations are generally 20, 35 or 45 mm thick or a combination of both. Thickness of the CLT panel typically varies from 60 mm up to 500 mm. The limiting factor on the CLT panel size is usually the ability to transport the product. For imported CLT, the size may also be limited to what can fit into a shipping container.

The cross-lamination provides relatively high strength and stiffness properties in both directions, giving it a two-way action capability, similar to a reinforced concrete slab. CLT has better structural properties than sawn timber and the cross-lamination process in CLT also increases the splitting resistance and connector strength. CLT is also known as X-lam ('cross lam') and 'massive or mass timber'.

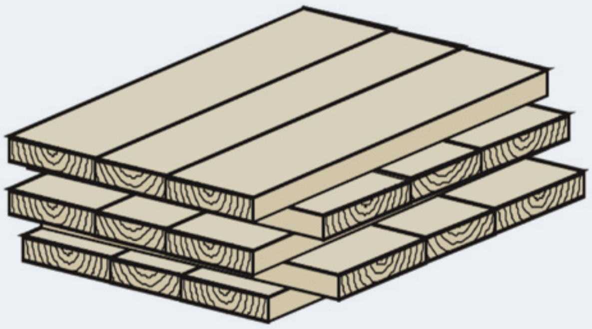


Figure 1.1: Layers of boards making up CLT.

Figure 1.2: 3 layer CLT panel after pressing. *Photograph: XLAM Australia*

1.1 History

CLT was initially developed in Switzerland and then in Austria in the early 1990s. In 1996, a joint industry-academia research effort in Austria resulted in the development of cross-laminated timber as it is known today.

Construction with CLT increased in the early 2000s. This was driven by the ‘green’ building movement, better efficiencies in production, and favourable building code changes in some jurisdictions. Leading countries in the use of CLT are Austria, Germany, Italy, France, Switzerland, Sweden, Norway and the United Kingdom, where it is typically being used in housing, multi-residential apartments and educational buildings.

Production is centred in Austria and Germany but there are also plants in Czech Republic, Italy, Finland Switzerland and Sweden. Outside Europe, plants have been established in Australia, Canada, New Zealand and the US.

1.2 CLT Benefits

The cross-lamination provides relatively high strength and stiffness properties in both directions, with a two-way action capability similar to a reinforced concrete slab. CLT has better structural properties than the sawn timber it is composed of, because the cross-lamination process “dilutes” the effect of knots and fibre deviation, while it increases the resistance to splitting and the connector’s holding capacity. The cross-laminating process provides improved dimensional stability and allows for prefabrication of wide and long floor slabs and wall panels. Therefore, CLT offers a number of advantages to developers, designers and builders with respect to comparable systems based on non-wood materials, including:

- significant reduced construction program durations
- improved installation speed for follow-on trades, i.e. mechanical, electrical facades and finishes
- high potential for off-site and/or on-site manufacturing, with more accurate tolerances
- lighter weight structures therefore lower requirements for foundations especially on weak soils or vertical extensions to existing buildings
- versatility for architectural design, i.e. overhangs and openings
- waste minimisation
- safer working environments on-site
- less demand for skilled workers on-site

CLT-based construction is typically faster and safer to erect on-site, and results in shorter construction times, which lowers development costs. Foundation costs can also be substantially reduced as CLT based construction is lighter than traditional concrete and steel construction. Erecting CLT is a quick and quiet process and takes up less space on-site and requires less truck movements compared to other building materials. This makes it suitable for infill sites and/or additions, increasing development viability of difficult sites.

CLT’s versatility as a building system appeals to architects and engineers. Panels can be used for all assemblies by varying the thickness. Long spans are possible, i.e. up to 7.5 m, with no intermediate support. Longer spans require additional support from beams or trusses. CLT is one-fifth the weight of reinforced concrete so mobile cranes can be employed, saving substantial erection, hire and labour costs.

Most of the processing of CLT occurs off-site at the factory, so there are fewer demands on construction labour on-site. The erection of the structure usually only requires minimal carpentry skills and power tools. Wet trades are largely eliminated, little waste is produced and there is less disruption to site neighbours. As fewer trades are carried out on-site, this contributes to a safer building site. CLT construction is timber-based and fasteners are fixed into timber, not concrete, so follow-on contractors require less time.

1.3 CLT Applications

There seems to be no limit to where CLT can be used. To date, CLT has been used in Australia for housing, apartments, offices, educational, student accommodation, hotels, childcare, libraries, community centres, schools and agricultural buildings.

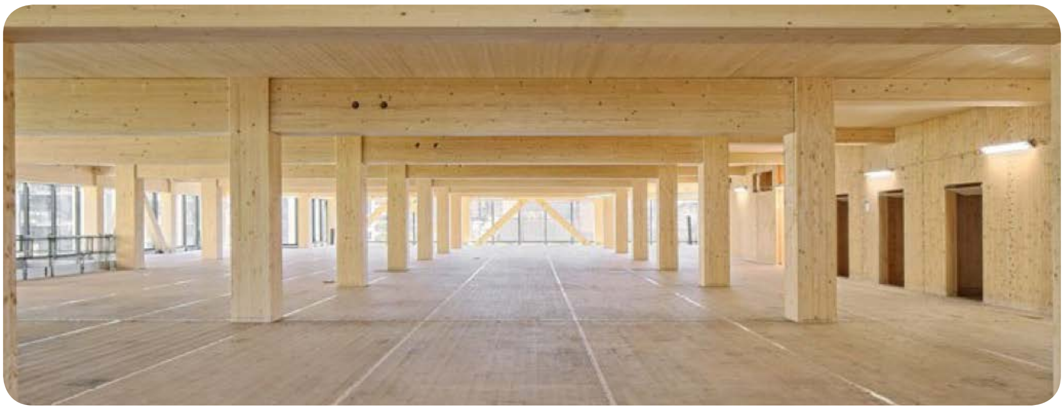


Figure 1.3: CLT used as a floor and walls inside office building, K5 Brisbane.
Photograph: Lendlease

Figure 1.4: CLT used for apartment constrcution, AVEO Norwest. *Photograph: Strongbuild*

Internationally CLT has been used in similar applications as Australia as well as some unique applications such as wind turbines tower, bridge decks, water reservoirs, pools and so on.

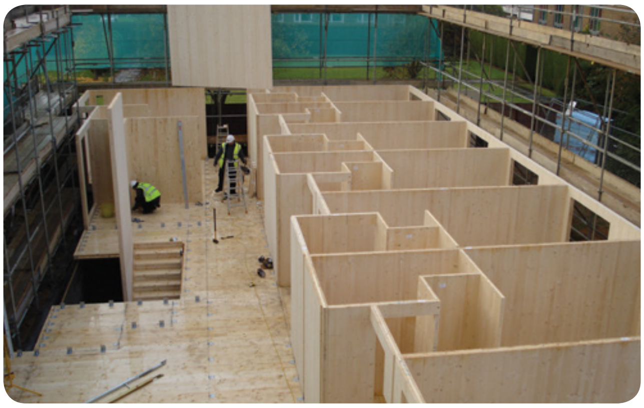
Figure 1.5: Water reservoir. *Photograph: Structurlam*

Figure 1.6: Mistissini Bridge, Canada using a CLT road platform.
Photograph: Nordic Structures

Figure 1.7: 100 m wind turbine tower
Photograph: Timber Tower

1.4 Compliance to the National Construction Code

The National Construction Code (NCC) has a number of Deemed-to-Satisfy (DTS) buildings solutions for Massive Timber, which includes products such as CLT, Glued Laminated Timber, and Laminated Veneer Lumber. The predominant DTS solution used is termed 'fire protected timber' where the minimum criteria for massive timber to use this DTS solution is that the element is to be not less than 75 mm in each direction and that the element is chemically bonded; the application is for residential or an office buildings up to an effective height of 25 m. For housing and low rise residential buildings there are separate NCC DTS solution placing no limits on CLT use. Where there is no direct DTS solution within the BCA, such as other building types or taller buildings, CLT may still use but via a performance solution pathway.

Left: 37 Snowfields. *Architect: DSDHA; Engineer: Structure Workshop; Contractor: Neilcott Construction; CLT Supply and Installation: KLH UK; Photograph : KLH UK*

Right: Woodside Lodge. *Architect: David Grindley Architects; Engineer: Tapsell Wade & Partners*

1.5 Environmental Performance and Occupant's Health Benefits

CLT manufactured from timber that is certified as harvested from sustainably managed forests is readily available. Sustainably sourced CLT has a number of positive environmental characteristics, including:

- carbon absorbed by the sustainably grown trees is stored long-term
- production of CLT results in less greenhouse gas emissions than production of many non-wood building materials.

Many recent CLT structures have benefited from these environmental considerations. For example, two high-rise residential buildings in London obtained preferential approval from local planning authorities because of CLT's positive environmental characteristics compared to concrete and steel. The use of CLT could allow extra points to be obtained from Australia's Green Building Council, GreenStar rating tool, for example 'innovation' or 'structural timber use'.

CLT also has equivalent or better characteristics than functionally equivalent concrete and steel systems in other aspects of environmental performance, such as thermal inertia and insulations, resulting in far more comfortable living conditions.

In addition, using timber has health and productivity benefits for building's occupants. A recent study by Pollinate: Workplaces: Wellness + Wood = Productivity[1] showed employees surrounded with natural wooden surfaces on average reported higher personal productivity, mood, concentration, clarity, confidence and optimism and were more likely to find their workplaces relaxing, calming, natural-feeling, inviting and energising, resulting in significantly fewer sick leave days.

Natural elements that can be brought indoors include stone and wood, water features, plants, natural light and imagery depicting the natural world. The principle brings into focus our innate attraction to nature and implies that we all have an inherent connection to the natural world through centuries of living in agricultural settings.

An additional benefit is the massive timber has a 'buffering' effect on moisture. When the indoor environment is drier massive timber elements releases water vapour and the opposite occurs when the indoor environment is wetter, the massive timber absorbs the water in the air. Therefore the interiors of massive timber buildings will typically remain in the comfortable zone of relative humidity for longer periods.

2

Manufacturing

2.1 Species Selection

The base species of timber used for CLT depends on where it is manufactured. Spruce is the main species used in Europe. Pine and larch can also be used on request. CLT plants in Canada or US use SPF (spruce-pine-fir) or Douglas fir. Production in New Zealand and Australia predominately uses radiata pine.

Although technically feasible, hardwoods are not presently used for CLT production as their ability to be fastened requires more work in erection, such as pre-drilling for screws. With that said, US hardwood producers have manufactured some hardwood CLT for demonstration purpose (Figure 2.1) and there has been an announcement of planned hardwood CLT production in Australia.

Figure 2.1: London Smile made from American tulipwood hardwood CLT
Photograph: Alison Brooks architects

There has also been early research work carried out on a hybrid combined softwood and hardwood CLT but it is not in production. Combined CLT and LVL systems have similarly been manufactured but tend to be on a project request basis.

2.2 Timber Laminates

Individual seasoned dimensional timbers are used, generally softwood. These are usually finger-jointed along their length to obtain the desired panel length and quality. Individual timbers can be edge-bonded together to form a timber plate before further assembly into the final panel.

2.3 Panel Assembly

Panel sizes vary by manufacturer and application, but typical widths are 0.6, 1.2, 2.25, 2.4, 2.7, 2.95 and 3.5 m (up to 4 m) while lengths up to 18 m or longer can be manufactured. Standard panel thicknesses are 57 to 300 mm, but some manufacturers can produce panels up to a thickness of 500 mm if required.

The outer layers of the panels are usually orientated to run parallel to the span or load direction. That is, for walls, the outer layers of the CLT panels are oriented in the short direct while for floor and roof CLT panels, the exterior layers run parallel with span direction, long direction.

One of the main differences between CLT manufacturers is their treatment of individual layers. Some manufacturers edge bond the individual dimensional timber together to form a layer before pressing each layer into the final CLT panel. Other manufacturers just face bond individual dimensional timber in layers and press all of them together into the final CLT panel in the one operation.

2.4 Adhesive

Generally, the choice of adhesives is dependent on manufacturers. The one-component polyurethane (PUR) adhesives are normally used as they are formaldehyde and solvent free.

Adhesives based on melamine urea formaldehyde (MUF) or phenol-resorcinol-formaldehyde (PRF) are also used. MUF is very-low formaldehyde emitting adhesive while PRF adhesives are ultra-low formaldehyde emitting, both meeting the most stringent low formaldehyde specification. Occasionally a mixture of adhesives are used, for example finger-jointed laminates often use different adhesives than used in the formation of the CLT panel.

2.5 Press

The right pressure is essential for both performances and aesthetic. Hydraulic presses are normally employed, however, the use of vacuum and pneumatic (compressed air) presses is also possible, depending on panel thickness and the adhesive used. Some presses also apply vertical and horizontal pressure to close the gaps between each board used to make up the CLT panel.

Figure 2.2: XLAM Australia's pneumatic CLT press. *Photograph: XLAM*

Figure 2.3: XLAM New Zealand's Vacuum Press. *Photograph: XLAM*

2.6 Panel Final Shape and Length

Computer numerical controlled (CNC) routers are generally used to cut the CLT panel to final length and width. Sometimes manufacturers also pre-cut openings for windows, doors, connections and service channels or ducts.

Figure 2.4: XLAM Australia's CNC. *Photograph: XLAM*

2.7 Surface Finish and Appearance

The assembled CLT panels are sometimes planed or sanded for a smooth surface finish but this is not carried out by all manufacturers.

CLT panels can be specified for appearance grade on the outer layer of the panel for situations where they will be seen on completion of the building. CLT panels with appearance grade outer layers are more expensive and generally where required are arranged with the manufacture. Appearance specifications vary so consultation with manufacturers is required before selecting an appearance specification.

Some manufacturers also have wire-brushed surfaces that remove the early wood leaving a textured surface. Again, consultation with manufacturer is required.

Figure 2.5: Wire-brushed surface of CLT. *Photograph: PlanetArk*

2.8 Transport Constraints for Panel Width and Length

Transportation may impose panel size limitations, so a discussion with the supplier is recommended before starting a building design. For example, imported CLT is generally transported via shipping container. The most commonly used standard shipping container (and the cheapest for transport) is 12.1 m × 2.35 m (internal length × width). The next most common is 5.89 m × 2.33 m (internal length × width).

The most efficient way of importing CLT is to use 2.25 m wide panels, are they can be packed horizontally into a standard container. CLT panel widths greater than 2.25 m have to be imported using open-top, out-of-gauge containers with the panels packed vertically rather than horizontally and they typically accommodate panel width up 2.95 m. Wider or longer panels require shipping using flat rack or MAFI containers. Open-top, flat rack or MAFI containers are more expensive than standard containers.

For standard containers, the maximum panel length is just less than 12 m, due to the overall internal length of the shipping container. Also, the maximum width is generally 2.25 m to allow the panel to negotiate the container's door opening. The length of panel requires consideration of using the maximum length of the panel as well as maximising the container used to transport the panels. For example, there is generally no cost penalty for 8 m long panels as they are cut out of a larger 'master panel' (see section 2.10 CLT Optimisation), which are normally 16 m in length. Therefore, two 8 m panels can be cut out of one 16 m master panel; however, 8 m panels are not an efficient size for standard containers. They are too long for 6 m containers and too short for 12 m containers.

For CLT manufactured in Australia, there are fewer size constraints and are directly dependent on road transport constraints. Ideally, panel sizes that don't require car escorts or special time of the day to travel cost less for transportation.

2.9 Site Access Constraints for Panel Width and Length

The constraints on the building site are often overlooked. Crane placement, trees or other buildings often interfere with the handling of large panels. Consideration should be given to these issues as well as transportation constraints.

2.10 CLT Optimisation

CLT optimisation needs to be considered during the design process. As discussed above, transport and site constraints affect panel size and costs. Panels are generally produced in the largest length that the manufacturer can make. These panels are termed 'master' or 'mother' panels and are optimised so that the least amount of material is wasted, as CLT cost is based not on the finished panel volume but the volume of CLT required to complete the order. Therefore, the most economical project will be delivered by considering transport constraints and the best use of master or mother panels.

Most CLT suppliers offer both optimisation and shop drawings services for a fee, or as part of the supply price of the product. The suppliers use their experience to calculate the most economical use of the master panel while considering transport constraints, usually resulting in project savings.

2.11 Mechanical Properties

As with other engineered wood products such as LVL and I-beams, the mechanical properties of CLT are timber species and manufacturer dependent. Mechanical properties are provided by each manufacturer on a proprietary basis, so reference should be made to each manufacturer's documentation during the design and specification process.

3

Design and Compliance

3.1 Standards and Codes

There is currently no Australian Standard that covers CLT manufacturing or installation.

Although CLT has widely been used in Europe it is only recently (late 2017), that a Standard on the manufacturing of CLT was published, *EN 16351:2015 Timber structures - Cross laminated timber*[2].

Prior to this, the generally approval process in Europe has been based on a European Technical Approval (ETA) Guideline that contains specific requirements for the product as well as test procedures for evaluating it prior to submission to the European Organisation for Technical Approvals (EOTA) in order to allow individual manufacturers to place CE (Conformité Européenne) marking on their products. The ETAs provided by European CLT producers and related documents provide a lot of information for designers.

Since European CLT varies from manufacturer to manufacturer, it is expected that the European Standard will take some time before it is widely adopted. During this time European CLT producers are likely to continue with the ETA approach.

The North American timber industry has as well developed a national manufacturing standard. This Standard covers the manufacturing, qualification, and quality assurance requirements for CLT - *ANSI/ APA PRG 320-2012 Standard for Performance-Rated Cross-Laminated Timber*[3]. Japan has also issued a product standard (JAS3079) in 2013.

3.2 Compliance to National Construction Code

Structural Design

The reference document in the NCC for timber structural design is AS1720.1[4]. This Standard may be applicable to CLT use, irrespective to what country the CLT was manufactured in, through the AS 1720.1 clause 1.3.1 (h) Other timber products and grade. This clause allows any timber product including CLT to be used within AS 1720.1, where the properties of the product are established by testing and evaluation methods consistent with AS/NZS 4063 Standard series. The only other provision is the modification factors for duration of load effect for strength and stiffness should be determined by authoritative research and the durability of adhesives used for manufacture should be appropriate for the exposure condition. Where CLT does not meet the conditions of this clause, it will require a performance solution approach.

Fire Performance

The NCC requires certain applications within a building to have a Fire Resistance Level. The NCC Provision A2.3 refers to NCC Specification A2.3 where a number of methods are detailed on how Fire Resistance Levels can be determined, i.e. by Standard Fire Test, an assessment based on a Standard Fire Test, calculations or by a referenced Standard. For CLT, the only options available to demonstrate compliance are test results or an assessment based on a Standard Fire Test. A Standard Fire Test is the test method described in AS 1530.4[5].

Regrettably the reference Standard for calculating Fire Resistance Levels for timber AS 1720.4[6] is not applicable to CLT as the Standard's scope is for Glue Laminated Timber, Plywood and Laminated Veneer Lumber compliant to their Australian manufacturing Standard only.

Where evidence is provided by fire test done by other International Standards that are similar to the Australian Standard test method, this information may be used as evidence for a performance solution or data for an assessment by an Accredited Testing Laboratory.

3.3 Design

Although CLT is a relatively simple building system it is new and uncommon to many designers, particularly when used in building applications that traditionally don't use timber based systems. To alleviate this most CLT suppliers in the Australian marketplace have proprietary documentation to assist designers as well as design services. Most CLT suppliers also have preliminary design guidelines and/or software tools to size CLT elements. WoodSolutions Guide No 44 *CLT Acoustic Performance*[7] provides a summary of CLT-based wall and floors systems that were tested using Australian acoustic products and methods.

4

CLT as a Building System

The high level of prefabrication and simplicity of handling CLT panels in construction enables a rapid erection time and reduces overall construction program durations. Openings for windows, doors, staircases and other utilities can be pre-cut using CNC machines at the factory.

Buildings are usually assembled on site. The prefabricated CLT panels are transported to the site, where they are connected with mechanical fastening systems such as self-tapping screws and brackets. It is also possible to assemble elements or modules of the building off-site and deliver completed segments of the building to the site. This speeds up the construction process even further.

Figure 4.1: Site assembled CLT core. *Photograph: Lendlease*

CLT is a flexible and lightweight building system, allowing for long spans and use in all assemblies (such as floors, walls or roofs) with a high degree of finishing preinstalled at the factory. Its ability to be used as a panelised and/or modular system makes it ideally suited for additions to existing buildings. CLT can be used jointly with any other material, such as light timber frames, heavy timbers, steel or concrete, and it accepts varied finishes.

Figure 4.2: Monash University Business School vertical extension. *Photograph: XLAM*

4.1 Building Layout

Each building material has its own efficient span and spacing and CLT is no different. For the most cost-efficient CLT building, it is necessary to consider efficiencies of the CLT in the layout of walls and support, etc, before committing to a design layout. Often, CLT is considered as an alternative construction method in a building that was first designed for concrete. In this case, the concrete building would in most cases be cheaper as the span and spacing are optimised for concrete not CLT.

Therefore, for a CLT design to be cost effective it needs to be designed initially with CLT in mind. The largest constraint on CLT design is generally the transport limitations discussed earlier that may restrict panel sizes, although this has recently been alleviated to some extend by local production. For example if an imported CLT floor panel is considered; where supports are greater than 6.0 m, it may not be possible to achieve continuous span floors as the CLT panel would need to be greater than 12.0 m, beyond a shipping container size. This results in simply supported floors that are deeper and more expensive. Consequently for imported CLT floor panels keeping the floor supports at 6.0 m or less results in design efficiencies.

The fundamental design of a CLT building is conceptually similar to the design of a lightweight timber frame platform construction systems, where wall support vertical loads and provide bracing. Floors take floor loads as well as acting as diaphragms to transfer loads to bracing elements or the core. Deflections and vibrations of floor elements need to be considered as they might often be the limiting factor in structural design. Connections are generally considered to be semi-rigid.

The basic rules for structural layout are:

- The building should have a modest ratio of height to footprint dimensions. Slender shapes are possible with some precautions.
- The arrangement of structural elements is similar to a series of ‘stacked boxes’ where the walls provide sufficient bracing and resistance to vertical loads.
- The floors act effectively as horizontal diaphragms with high in-plane rigidity and resistance to out-of-plane buckling.
- CLT panels offer a lot of space to position connections offering design efficient both in the vertical and horizontal directions.

Experience has shown the most efficient CLT structure occurs when the selection of the supplier is made early. Juggling issues such as panel size constraints, differences in CLT properties, etc, are reduced once a CLT supplier is selected.

5

The Building Process

The CLT panels are divided into ‘elements’. These elements are usually numbered and shipped according to an assembly plan. Installation typically needs a mobile crane, light power tools and a small crew of riggers and/or carpenters and mobile crane operators.

5.1 Planning

The accurate planning of the supply, delivery and construction phases is important to get all the benefits that CLT structures brings to a project. Efficiencies in erection are achieved when due consideration and time is given to accurately planning and documenting the sequence of delivery, on-site handling operations and assembly methods. The following is a non-exhaustive list of considerations for the planning for a CLT structure:

- Design CLT elements to be the largest size possible to reduce crane movements on site. CLT’s lightweight panels can be fabricated and delivered to site as large elements.
- Reduced site storage by just-in-time delivery scheduling, therefore a factory loading order that considers the unloading sequence and pre-fitting of lifting devices is recommended. CLT suppliers can provide an analysis of the construction sequence and lifting requirements as part of their services.
- Pre-install connectors and other items on the ground or off-site.
- Pre-fitting of linings on both CLT surfaces, slots and holes is easy and quick, as well as moisture protections.
- Assemble items on the ground or off-site.
- Practise the lifting sequence virtually before building on site. Virtually modelling the building’s assemble identifies road blocks and allows correction before being on-site.
- CLT’s interface with concrete slows things down by half. Think about better ways to connect timber to concrete.
- CLT’s reduced weight decreases crane loads compared to other panel construction materials, allowing for smaller crane requirements and shorter use periods.
- Early provision of a stable structure without the need of temporary props allows the follow-on trades to commence earlier.
- Should any unforeseen change need to happen on site, e.g. the position of an opening, then CLT allows quick and easy modification with hand-held carpentry tools.

5.2 Site Assembly

For general construction, the delivery truck or trailer will park near the structure while each panel is offloaded and fixed into place. Panels are loaded onto the truck or tailer in the reverse sequence that they will be required for installation. Where it is not possible to install CLT panels immediately, they can be off-loaded and stored off the ground, under a waterproof covering. Due to the light weight of the panels, it is also possible to use the building itself as a temporary storage place, e.g. lift a bundle of panels on the floor where installation is progressing and let the truck leave. Storage and delivery options should be fully explored to minimise double handling.

Figure 5.1: Trailers used to store panels before installation on site. *Photograph: TDA*

Panels are lifted into place using pre-inserted hooks or slings for walls, while floors are usually lifted with screws driven into the panel surface and specific hooks that clamp onto their screw head.

Walls are usually placed on top of a grout bed for CLT/concrete connections and foam, cork or elastomeric strips for CLT/CLT connections where fixing plates are positioned along the line of the walls. Elastomeric supports may also be used to reduce flanking noise.

Sealing tapes are sometimes applied to the end grain and connections of CLT panels to reduce potential for moisture uptake and to form airtight constructions.

Figure 5.2: Slings and brackets used to support CLT panels during lifting.
Photograph: WoodSolutions

The panel-to-panel connections can be pre-cut and established through half-lapped, single or double splines made with engineered wood products, or made with steel connectors; plates, angles and screws.

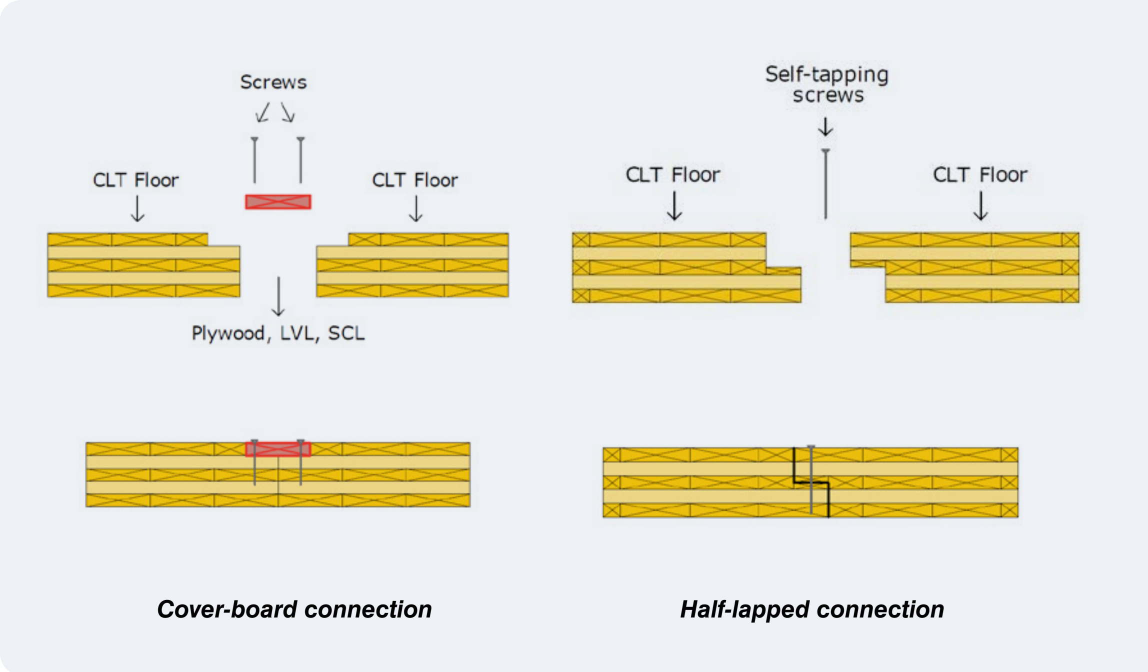


Figure 5.3: Methods to join CLT floors panels together.
Source: CLT Handbook: Cross-laminated Timber (U.S. Edition 2013) FPInnovation

Metal brackets, hold-downs and plates are typically used to transfer forces. Innovative connection systems can also be used, including glued-in rods or plates, mechanical (clips, dovetail plates, etc) and carpentry connection systems.

Figure 5.4: Wall to floor connection. *Photograph: TDA*

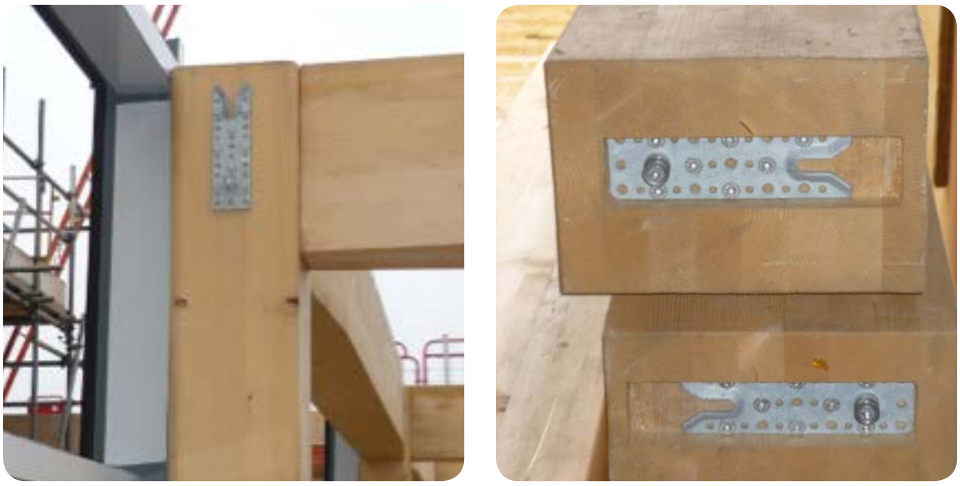


Figure 5.5: Specialist Timber Connector. *Photograph: TDA*

Floor and walls are brought together with clamps for their final placement.

Figure 5.6: Special clamp used to align CLT floors. *Photograph: WoodSolutions*

5.3 Utilities

Electrical, HVAC and water distribution services are typically placed within suspended ceilings, false walls or specific cavities. Brackets used to support services are usually easy to install as they are screwed into timber with lightweight tools, instead of fixed to concrete with expensive anchors and heavy tools, thus resulting in shorter construction programs and optimised costs.

Using CLT panels also for the lift shafts and staircases is normally the preferred option, as the panels are strong and stiff enough to provide sufficient resistance to lateral loads and avoids the need to introduce wet trades into the project.

Figure 5.7: Lift shaft in Stadthaus, Murray Grove. *Architect: Waugh Thistleton; Engineer: Techniker; Contractor: Telford Homes; CLT Supply and Installation: KLH UK; Photograph: TDA*

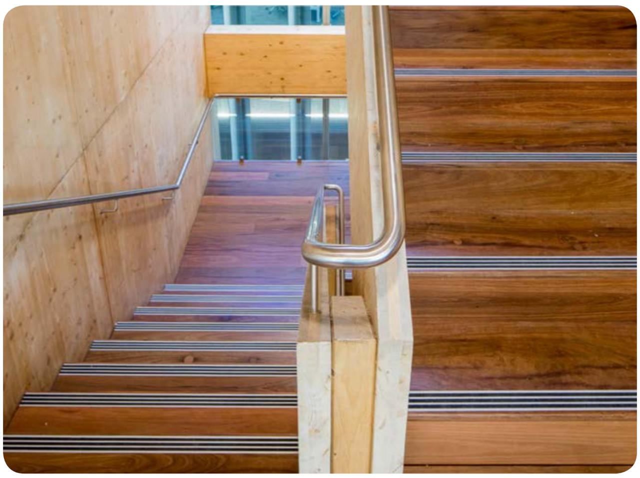


Figure 5.8: Fire stair in International House, Sydney. *Photograph: Lendlease*

Figure 5.9: Figure 4.8: Lift installed in CLT shaft in International House, Sydney.
Photograph: Lendlease

6

Properties of CLT Assemblies

6.1 Structural Performance

CLT panel's strength and stiffness are predominately produced from the outer load direction laminations. Transverse and central laminations primary function is to hold the outer lamination apart and provide the panel's stability.

Timber boards used to manufacture CLT are generally not homogeneous throughout the panel and the layup, thickness and grade vary from manufacturer to manufacturer. As stated above there is no Australian manufacturing standard for CLT, therefore CLT panel properties are proprietary in nature. Reference to the supplier for their individual properties is required.

Many of the CLT suppliers have preliminary size information that can be used to initially design CLT buildings.

6.2 Fire Performance

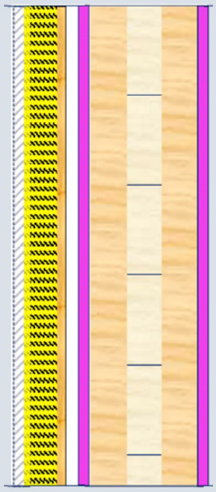
CLT assemblies have excellent fire resistance due to the thick cross-sections that char at a slow and predictable rate when exposed to fire. CLT construction typically has fewer concealed spaces within wall and floor assemblies than framed construction, which reduces the risk of hidden fire spread.

The NCC has a number of deemed-to-satisfy fire solutions suitable for CLT use. The predominate DTS fire solution is for walls within buildings with an effective height of 25 m or less, sprinkled and protected by fire protective coverings. This solution is generally termed fire-protected timber and currently is applicable for residential and office buildings. Within this provision, two timber systems are recognised Massive Timber and Timber Framed. CLT fits in the Massive Timber provisions. CLT fire rated solutions may also be used for other NCC DTS solutions for low-rise timber buildings as well as housing.

Generally, the NCC's Fire Protected Timber DTS solution requires a layer of fire-resisting plasterboard as the fire protective covering. Fire-resisting plasterboard is not the only fire protective covering that can be used. Any non-combustible covering that resists the temperature rise on the timber surface for a period of time can be used. The time for this temperature rise varies depending on location and application within the building. Refer to WoodSolutions Guide No 37[8] and No 38[9] for more information on this NCC DTS. The fire resistance level required for fire protected timber systems are no difference to that required by other materials.

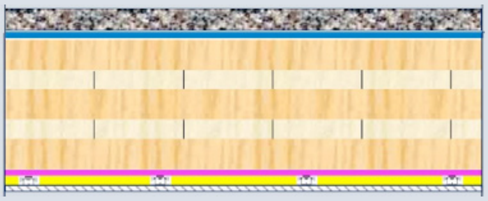
The fire protective covering used to protect CLT can also be used to reduce the thickness of the wall or floor CLT panel required for the fire design. Standard fire tests have been conducted on wall and floor systems, see Figure 6.1 for common solutions.

Configuration



System	Test	Lining	Stud Frame	Thickness (mm)	R_w	$R_w + C_{tr}$	STC
W02-05	T1617-89	2x13mm standard plasterboard	70mm timber stud 20mm gap	238	58 - 59	**52**	58 - 59
W03-04	T1617-44	2x13mm standard plasterboard	64mm steel stud 20mm gap	232	59 - 60	**52**	60 - 61
W03-05	T1617-46	1x13mm sound-rated plasterboard	64mm steel stud 20mm gap	219	58 - 59	**50**	59 - 60
W03-06	T1617-47	2x13mm sound-rated plasterboard	64mm steel stud 20mm gap	232	60	**53 - 54**	60 - 61

Figure 6.1: Typical CLT fire and sound rated wall system

Configuration	
	Floor 40mm screed 10mm rubber underlay 140mm Cross-Laminated Timber (CLT) 16mm fire-rated plasterboard 67mm furring channel ceiling with Resilient mounts 50mm glasswool insulation 13mm standard plasterboard

System	Test	Floor Covering	Thickness (mm)	R_w	$R_w + C_{tr}$	STC	$L_{n,w}$	IIC
F11-01	T1617-52	Bare screed	286	60 - 61	**52 - 54**	60 - 62	**53 - 55**	55 - 57
F11-03	T1617-53	7mm laminate timber floor 3mm foam underlay on Screed	296	60 - 61	**51 - 54**	60 - 61	**52 - 53**	54 - 57

Figure 6.2: Typical CLT fire and sound rated floor system

As CLT is timber, there are some instances where its inclusion in buildings will not meet the Deemed-to-Satisfy fire performance requirements in the NCC, for example exposed CLT used for walls within the fire protected timber DTS. Where this occurs a Performance Solution compliance path is required. A number of structures have taken this path to date and have obtained approval. For further information, refer to WoodSolutions Guides No 2[10], No 3[11], No 17[12], No 18[13] and No 19[14].

6.3 Acoustical Performance

The acoustic performance of CLT is excellent because of timber's natural damping ability and, if considered with reference to the mass per unit surface area, it is better or equivalent to other forms of panel construction. As with other forms of construction, the CLT systems are not entirely reliant on the CLT itself to deliver the required performance. That is, overall performance depends on providing independent leafs of construction via two CLT panels, or a CLT and framed construction with cavities generally having insulating materials included.

Floor construction generally includes a separated ceiling below the CLT panel. Floor acoustics performance can be increased in a number of ways. In Europe, concrete screeds, battens, dry sand or gravel and other proprietary materials are sometimes used, that may include floor heating. These systems generally easily exceed the NCC minimum requirements, with the ultimate choice of system dependent on the level of acoustic performance required for the project. Refer to Figure 19 and 20 for typical wall and floors system incorporating CLT as well as WoodSolutions Guide No 44[7].

As with all building structures, some corrective measures during construction are needed to reduce flanking noise. Polyurethane sealant damping strips or laminated natural rubber or cork in the junction of the floor-to-wall will reduce flanking noise as well as make the structure air tight. Having discontinuous walls across stories and discontinuous floors across units helps prevent flanking noise. Installing floating floors may also assist. All these acoustic strategies are consistent with any building system, irrespective of the material of construction used.

Figure 6.3: Polyurethane flanking strip under CLT floor. *Photograph: Rothoblaas*

6.4 Thermal Performance

CLT has the same fundamental thermal properties as the timber it is made from. Timber generally has a low thermal conductivity, high thermal inertia and strong moisture buffering ability. It also reduces problems such as thermal bridging from the internal to the external environments or the reverse, resulting in reduced heat transfer and energy wastage.

CLT-based exterior walls will also provide a degree of insulation higher than that provided by exposed solid masonry construction, which can reduce energy use in buildings such as apartments that are not constantly occupied. European studies and built experience suggest that CLT provides a degree of thermal mass for a building; due to increased wall system density compared to framed construction.

External walls usually have a weather-protecting layer of masonry or commercial façade, such as cementitious panels, wood based panels or metal cladding. In the cavity between the exterior weather protecting envelop and CLT, insulation is placed to obtain the desired level of building envelope thermal efficiency. As with all building materials and systems, care is required to consider where condensation may occur within the external wall cavity and therefore vapour permeable materials are always preferred. Where dew point calculations are undertaken, the dew point should occur on the outside of the vapour permeable membrane, never in the CLT or interior of the building.

Due to a high degree of manufacturing precision, good air tightness may also be achieved with CLT. Foam tape is normally used at the joints for this purpose.

6.5 Durability

As the species used for CLT production is generally softwood, which is generally of low natural durability when used untreated in exposed applications, it is not recommended to directly expose the panel to exterior conditions. Normally, CLT buildings have a weatherproof layer of masonry or commercial facade. A cladding of naturally durable or appropriately preservative-treated wood product may also be used.

6.5.1 Termite Resistance

CLT's termite resistance performance is considered the same as would apply to the same timber species used in timber-framed construction. CLT is predominately made from termite susceptible timber species but some CLT producers can preservative treat the CLT on demand. If termite protection is required, the building should be protected in accordance to the principles contained in AS3660[15].

6.5.2 Decay Resistance

Again the base timber species used predominately for CLT production are non-durable. CLT made from spruce or Douglas fir are difficult to preservative treat to Hazard Level 3 or higher. Australia and New Zealand produced CLT are normally from pine timber such as radiata that can have the base lamination preservative treated to Hazard Level 3 or higher if required.

6.5.3 Weather Protection

Due to the quick erection time of CLT-based systems, the short-term exposure of CLT to weather will not usually have a long-term effect. The work sequence should be planned to reduce weather exposure of the panels as much as possible and this should be maintained until the building is closed in. During construction, wall elements can be protected with vapour barriers or the building's scaffolding can be wrapped to form this protection. Other strategies could be employed, such as a coating system for the construction period only.

As CLT buildings are generally air tight, and consequently water tight, strategies to deal with storm water during construction are required. Ponding water should be brushed off as early as is practical. As discussed above, long-term direct weather exposure of CLT is not recommended.

6.6 Seismic Performance

In 2008 the National Research Council of Italy, Trees and Timber Institute (IVALSA) tested three and seven-storey, full-scale CLT buildings in a Japanese research facility that has the largest quake simulation 'shaking table' in the world[16]. Each building was exposed to large simulated earthquakes subjected to severe earthquake motions, like that of the devastating Kobe earthquake with a magnitude of around 7.0.

In the case of the three-storey building, which was tested 26 times, damages to connections where achieved as predicted and no unforeseen damages was observed in the CLT panels, thus allowing for a 'Zero Damage Design' approach to be developed. This means the structural safety and serviceability of the building is maintained and repairs are possible in those joints that are deemed to be yielding under the design quake loads.

Based on the previous experiences, in the case of the seven-storey building there was no residual deformation after 14 test quakes, again the Zero Damage Design approach was validated. The maximum inter-storey drift was 40 mm (1.3% of ceiling height), while the maximum lateral deformation at the top of the building was only 287 mm. The CLT buildings showed ductile behaviour and good energy dissipation, as expected. Such behaviour was both influenced by the cross-lamination effect and by the design of the connections, which can be repaired or re-integrated after a quake event while the CLT panels are only damaged for a few millimetres around the connectors by embedment (crushing). Further work has recently been done on seismic performance in North America[17] and Japan.

Figure 6.4: 7 storey CLT building on a shake table
Image: National Research Council of Italy, Tree and Timber Institute (IVALSA)

6.7 CLT Manufacturers and Further Information

CLT availability into the Australian market is rapidly changing with local and imported product available. There are currently two manufacturers of CLT in Australia, one on the east coast and another on the west coast. Imported CLT is predominately supplied from Europe and New Zealand.

As manufacturers and suppliers of CLT are rapidly changing updated information and details are available from the Suppliers listing on the WoodSolutions web site: www.woodsolutions.com.au

7

Case Study: Forté

Figure 7.1: Completed Forté apartments. *Photograph: Lend Lease*

7.1 Design Professionals

- Architects: Lend Lease
- Structural Engineers: Lend Lease
- Services Designers: Lend Lease
- Fire Safety Engineers: Scientific Fire Services
- Acoustic Engineers: Renzo Tonin
- CLT Supply: KLH UK
- Building Surveyor: City of Melbourne – Melbourne Certification Group

7.2 About Forté

Forté Living is a 10-storey apartment building made from cross-laminated timber. At 32.2 m, it is currently the world's tallest timber apartment building and also the first Australian building constructed with CLT.

The building is made from 759 CLT panels made of European spruce (*Picea abies*), weighing 485 tonnes. The European spruce was harvested and panels manufactured in Austria, before being shipped to Australia in 25 shipping containers.

The timber structure was connected with 5,500 angle brackets using 34,550 screws.

Forté's ground and first-storey floor slab were constructed from geoploymer concrete. This was due to the larger spans required in the retail space and the need for general good practice to have the timber away from the ground.

Once the concrete had set, the CLT panels were transported from their storage site a short distance away. The panels were raised into their final position and connected together with screws and metal brackets. The first panels erected were those forming the stair and lift core, which were stood vertically. When these core panels were in place, others were laid on their sides to form internal and external walls. The panel width forms each storey height of the building.

Panels were laid on top of the walls to form floors. This process was repeated until the full height of the building was reached. The roof was constructed the same way as each floor.

Figure 7.2: Forté under construction. *Photograph : Lend Lease*

Left: Figure 7.3: Interior view of Forté prior to internal linings being affixed. Steel elements projecting into corridor are pre-fabricated bathroom pods. *Photograph : Lend Lease*

Right: Figure 7.4: Completed Interior of Forté Apartment. *Photograph : Lend Lease*

The exterior of the building is clad with metal commercial façade consisting primarily of AluBond®; however, parts were also covered with Lysaght® products and recycled hardwood timber. These finishes provide the rain-screen protection to the CLT structure.

The balconies are an extension of the CLT flooring of the main building structure. The CLT is covered with concrete screed and a waterproof membrane is finished with tiles. The CLT used in each apartment's balcony floor is exposed on the underside, with a timber stain and seal polyurethane used to protect the timber.

The interior of the apartments is lined with plasterboard and painted. Other than a featured internal CLT wall, there is no indication that the building is constructed from timber.

The featured CLT wall is sealed with a clear coat to blend in with the light colours used elsewhere in the interior. An Australian hardwood blackbutt engineered wood floor is used throughout the living areas.

7.3 Environmental Benefits

All CLT used in Forté is harvested from sustainably managed spruce forests in Austria while the blackbutt floor is from sustainably managed forests in Austarlia.

A full life cycle assessment by staff of RMIT University compared Forté with a standard apartment building constructed with reinforced concrete. The carbon footprint of Forté, including the transport from Austria, was 22% lower if carbon storage in the timber was included and 13% lower if carbon storage was not included. If the carbon footprint of the building materials alone were considered, the carbon footprint of the Forté building was 30% lower than the concrete-reinforced building.

The 485 tonnes of CLT used in the building construction equates to 216 tonnes of stored carbon that absorbed 792 tonnes of CO_2 during its growth (based on 12% moisture content and carbon content of 50.5%, by weight. In comparison to a standard concrete and steel building, Forté reduces CO_2 emissions by more than 1,451 tonnes, the equivalent to taking 407 cars off the road for a year.

(This calculation is based on information from the Australian Bureau of Statistics[6] and the Australian Government greenhouse gas emissions calculator 2008, estimating average CO_2 emissions for a passenger car in one year at 3.56 tonnes.)

The building also achieved Australia's first 5-star Green Star Multi-Unit Residential As Built rating.

7.4 Fire Resistance

Fire resistance is a key issue. When this building was constructed, the CLT system used did not meet the deemed-to-satisfy requirements of the NCC, requiring a performance solution. CLT walls are generally comprised of CLT panels 128 mm thick with 13 mm fire-resisting plasterboard direct fixed to both sides. The bare timber walls used as a feature in the Forté apartments are 128 mm thick CLT. All required walls achieve the required deemed-to-satisfy fire rating FRL of 90/90/90.

The floors are generally 146 mm thick with two layers of 16 mm fire-resisting plasterboard, again direct fixed. The floors exceed the required deemed-to-satisfy fire rating FRL of 90/90/90.

The external walls use a combination of fire-resistant plasterboard and the calculated char capacity of timber itself. Fire safety engineering analysis considered them to achieve the deemed-to-satisfy fire rating from the inside. However, the analysis showed it did not meet the deemed-to-satisfy requirements for a fire exposure from outside in some circumstances. The outer layer of CLT to one elevation where the building is exposed within 6 m of another allotment is thickened to provide the resistance to fire from that direction.

Penetrations through all fire-rated elements are dealt with by the usual methods, however, extensive testing according to the Australian Standards was done to demonstrate compliance with the Standard and applicable requirements of Part A of the NCC – Volume One.

Sprinklers have also been used. They were not included as deemed-to-satisfy but allowed consideration of particular concessions according to Victorian variations to the NCC. It is also noted that sprinklers provide social sustainability to the occupants of the building through minimising any disruption or relocation if there is a fire.

7.5 Acoustics

The system used in Forté meets and exceeds building code deemed-to-satisfy minimum requirements. The floors use a combination of products to deal with airborne sound as well as impact noise. The floors in the living area are engineered timber and any hard surface floors require greater impact noise consideration.

Forté uses a number of techniques – such as concrete screed topping, direct fixed and/or resilient mounted plasterboard and suspended ceiling and resilient mat – to improve airborne and impact noise, similar to standard construction. A thicker than normal concrete screed was used to match the floor height of the pre-fabricated bathrooms that were also used on this project.

Bulk insulation has been placed in the cavity of the suspended ceiling and direct fixed plasterboard. Wall systems use the addition of frames lined with plasterboard to provide acoustic isolation between apartments.

Figure 7.5: Cross section model of floor construction used in Forté.
Photograph: TDA

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References & Further Reading

References

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2. EN 16351:2015 *Timber structures - Cross laminated timber*.
3. CLT - ANSI/APA PRG 320-2012 *Standard for Performance-Rated Cross-Laminated Timber*
4. AS 1720.1. *Timber Structures Part 1: Design Methods.*
5. AS 1530.4 *Methods for fire tests on building materials, components and structures Part 4: Fire-resistance test of elements of construction.*
6. AS 1720.4 *Timber Structures Part 4: Fire resistance for Structural Adequacy of Timber Members*.
7. WoodSolutions *Guide No 44 CLT Acoustic Performance.*
8. WoodSolutions *Guide No 37 Mid-rise Timber Buildings Class 2, 3 and 5 Buildings.*
9. WoodSolutions *Guide No 38 Fire Safety Design of Mid-rise Timber Buildings Basis for the 2016 changes to the National Construction Code.*
10. WoodSolutions *Guide No 2 Timber-framed Construction for Multi-residential Buildings Class 2 & 3.*
11. WoodSolutions *Guide No 3 Timber-framed Construction for Commercial Buildings Class 5, 6, 9a & 9b.*
12. WoodSolutions *Guide No 17 Alternative Solution Fire Compliance, Timber Structures.*
13. WoodSolutions *Guide No 18 Alternative Solution Fire Compliance, Facades.*
14. WoodSolutions *Guide No 19 Alternative Solution Fire Compliance, Internal Linings.*
15. AS3660 *Termite management – New building work.*
16. Ceccotti, A. (2010) *Cross Laminated Timber Introduction to Seismic Performance, Trees and Timber* Institute IVALSA-CNR National Research Council, Italy. Available at www.bcwood.com/resources/cross-laminated-timber-symposium-presentations/
17. Popovski (2010) *Seismic Performance of CLT Construction. FP Innovations*. Available at www.cecobois.com/index.php?option=com_content&view=article&id=315&Itemid=199.

Further Reading

The WoodSolutions Guides are available to download for free from www.woodsolutions.com.au in the resources section.

No 2 Timber-framed Construction for Multi-residential Buildings Class 2 & 3

No 3 Timber-framed Construction for Commercial Buildings Class 5, 6, 9a & 9b

No 17 Alternative Solution Fire Compliance, Timber Structures

No 18 Alternative Solution Fire Compliance, Facades

No 19 Alternative Solution Fire Compliance, Internal Linings

No 37 Mid-rise Timber Buildings Class 2, 3 and 5 Buildings

No 38 Fire Safety Design of Mid-rise Timber Buildings Basis for the 2016 changes to the National Construction Code

No 44 CLT Acoustic Performance

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Fire Safe Design of Timber Structures

Compliance with the National Construction Code

Technical Design Guide issued by Forest and Wood Products Australia

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- Fire compliance
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- Thermal performance

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Cover image: Forte apartments Melbourne, courtesy FWPA

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Table of Contents

Introduction

Timber is used for many building applications and has numerous advantages over other building products, including; its environmental sustainability credentials, light-weight compared to most structural materials, speed of construction, and aesthetics.

This has led to an increased interest in the use of structural timber for mid-rise buildings (up to an effective height of 25m) and high-rise buildings in Australia in addition to the more established applications for low-rise buildings and single dwellings.

Changes to the National Construction Code (NCC) in 2016[1] and 2019[2] introduced for the first time in Australia, *Deemed-to-Satisfy* (DTS) pathways for demonstrating compliance for mid-rise timber buildings based on the concept of fire-protected timber. Refer Figure 1 for the NCC height limits that correspond to low, mid, and high-rise construction.

Low-rise timber buildings
typically are buildings of:
Type B or C construction (1 or 2 storey)

Mid-rise timber buildings
have an effective height of not more than 25 metres.
Typically, they are 3-8 storeys high (the maximum number of storeys depends on the floor-to-floor height)

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

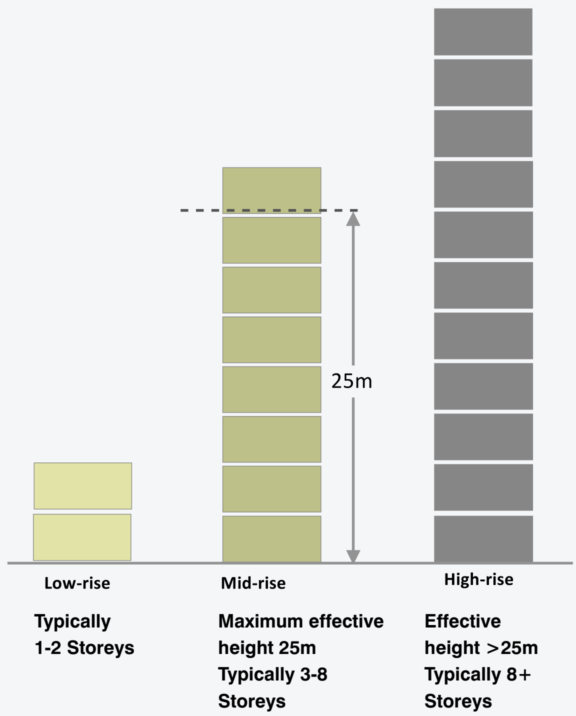


Figure 1: NCC height limits corresponding to Low, mid, and high-rise timber buildings.

Note: The NCC provides a relaxation allowing some 3-storey Class 2 or 3 buildings to be of timber frame construction

Detailed Guidance on the application of NCC [3] *Deemed-to-Satisfy Provisions* to low-rise and mid-rise timber buildings are provided in the following WoodSolutions Technical Design Guides.

- WoodSolutions Technical Design Guide 1 Timber-framed Construction for Townhouse Buildings (Class 1a)
- WoodSolutions Technical Design Guide 2 Timber-framed Construction for Multi-residential Buildings (Low-rise Class 2 & 3) – under revision at the time of preparation of this Design Guide
- WoodSolutions Technical Design Guide 3 Timber Framed Construction for Commercial Buildings Classes 5, 6, 9a & 9b – under revision at the time of preparation of this Design Guide (This guide is temporarily unavailable as it is being revised).
- WoodSolutions Technical Design Guide 37R [4] - Mid-rise Multi-residential buildings (Class 2 and 3)
- WoodSolutions Technical Design Guide 37C [5] - Mid-rise Commercial and Education buildings (Class 5,6,7,8 and 9b,including Class 4 parts)

- Wood Solutions Technical Design Guide 37H [6] - Mid-rise health-care buildings (Class 9a and Class 9c)
- WoodSolutions Technical Design Guide 42 [7]. - Timber Aged Care Buildings (Class 9c).

Note: Guide 42 describes an alternative DTS pathway to the fire-protected timber solution for Class 9c aged care accommodation

This Guide (Design Guide 17-2021) introduces fire safe design approaches for timber structures in Australia. The primary focus is compliance with the NCC Volume One which provides requirements for the technical design and construction for all multi-residential, commercial, industrial, and public assembly buildings and their associated structures (Class 2 to 9 buildings) but some content can also be applied to single dwellings and associated structures.

Other design objectives may also apply and are discussed where appropriate, highlighting the need for building designers to consider all relevant legislation and design objectives throughout the building life-cycle in a holistic manner.

Document Overview

This Guide is intended to provide an introduction to the fire safety design of timber buildings in compliance with the NCC Volume One. It is suitable for a broad range of practitioners and students including;

- Fire Safety Engineers
- Building Certifiers
- Structural Engineers
- Fire Authorities
- Architects, and
- Building Consultants

This Guide is part of a series of three guides that have been written in 2021 to reflect the significant changes to fire safety regulations and recent research relating to the performance of timber when exposed to fire. This Guide provides a general review of the NCC compliance pathways and Assessment Methods before focussing on how these pathways and Assessment Methods can be applied to timber buildings and elements of construction to verify compliance with the NCC.

The other two design guides in the series are listed below and have greater technical content more suited to fire and regulatory specialists such as fire safety engineers, building certifiers and fire authorities.

- Wood Solutions Technical Design Guide 18 - Fire Safe Design of Timber Structures - Methods of Analysis and Supporting Data (2021) provides more detailed information relating to the design and *Assessment Methods* described in this Guide along with supporting data predominantly used during the development of the compliance pathways for timber
- Wood Solutions Technical Design Guide 19 – Fire Safe Design of Timber Structures - Worked Examples of Performance Solutions (2021) provides worked examples of the analysis and *Assessment Methods* that can be applied to typical *Performance Solutions*.

Below is a summary of the content of this design guide.

Chapter 1 includes an overview of the design process to provide a context for the application of the NCC. The need to consider a broad range of other drivers and constraints based on applicable legislation and stakeholder requirements and the importance of considering implementation, commissioning and through life performance of buildings is also discussed.

Chapter 2 provides a general introduction to compliance pathways under the NCC, including DTS and *Performance Solutions*, and Assessment Options.

Chapter 3 describes the NCC compliance pathways available for timber buildings

Chapter 4 describes the various options available for the design of Structural Elements and Barriers to resist fire. It also describes how structural design loads are derived for fire conditions and default load levels can be established for fire testing and other methods of assessment based on NCC referenced design standards.

Chapter 5 reviews the high level *Assessment Methods for Performance Solutions* relating to the fire performance of timber buildings including *Verification Methods* CV1 to CV4 and comparative and absolute assessments against the *Performance Requirements*. In relation to absolute assessments proposed, changes to the NCC relating to the quantification of *Performance Requirements* are described.

Chapter 6 reviews the NCC *Assessment Methods* for verification of compliance of DTS Solutions relating to timber elements of construction. These *Assessment Methods* should also be applied, as appropriate, to the detailed documentation for *Performance Solutions*.

Additional information, definitions and references are provided in the Appendices.

1

Building Design Process

1.1 Addressing Critical Drivers and Constraints During the Design Process

When undertaking a fire safety design for any building it is critical for the designer to understand the objectives of key stakeholders and the key drivers and constraints that apply to the project.

Critical drivers and constraints should be identified through consultation with key stakeholders at the start of the design process, from which the essential design criteria can be derived. These should be the focus throughout the development of the design and incorporated in the design documentation.

Identifying key drivers and constraints early in the design process facilitates the adoption of a holistic approach to design such that synergies between the various drivers and constraints can be exploited and design constraints can be managed in a cost-effective manner.

Compliance with the relevant design drivers and constraints should then be checked for both the NCC drivers and constraints as well as other criteria that have been derived once the fire safety strategy has been resolved during the design process and as the supporting documentation is developed. This process is shown schematically in Figure 2.

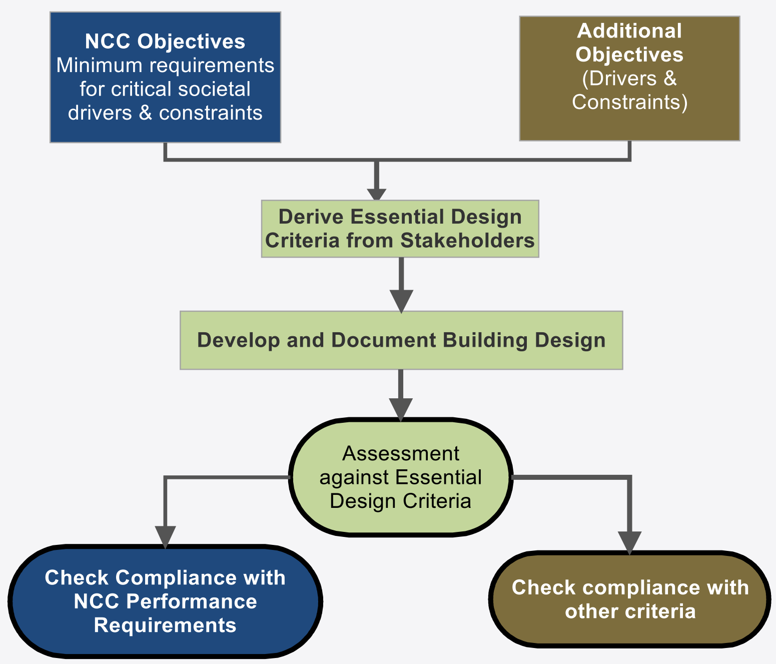


Figure 2: Addressing Critical Drivers and Constraints during the Design Process.

1.2 Role of the National Construction Code

The NCC sets minimum community standards for a range of drivers and constraints with the goal of addressing community expectations with respect to criteria such as:

- Health and Safety
- Amenity
- Accessibility
- Sustainability
- Protection of Other Property

Note: Whilst the NCC provides an essential consolidation of technical provisions relating to fire safety in buildings, which is the primary focus of this Design Guide, practitioners need to also identify and address additional drivers and constraints that may be required to be satisfied by other legislation (e.g. Disability Discrimination and Work Place Health and Safety legislation), in addition to other project stakeholder requirements and a general duty of care to provide an acceptable level of safety.

The National Construction Code (NCC) was developed to provide a uniform set of minimum technical requirements and standards for the design and construction of buildings and other structures throughout Australia. It is given legal effect by each of the State / Territory regulatory systems who are responsible for administering and regulating these matters under the Australian Constitution. As a result, administrative provisions, and to some extent technical provisions can vary between the States and Territories.

The NCC is a performance-based code which primarily applies to the design and construction of new buildings (and new building work in existing buildings) throughout Australia. The performance based NCC provides the flexibility to address other drivers and constraints in a cost-effective manner without compromising the NCC requirements.

The relationship of the NCC to regulatory and non-regulatory drivers and constraints is shown in Figure 3.

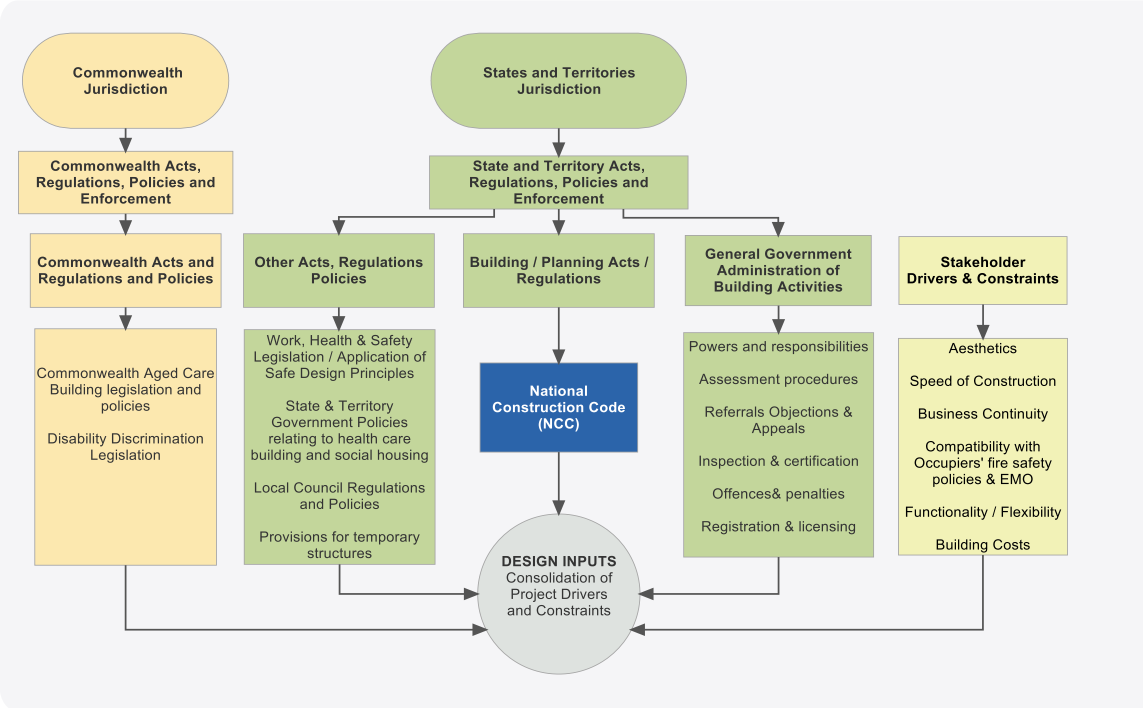


Figure 3: Relationship of the National Construction Code to other Regulatory and Non-Regulatory Drivers and Constraints.

The Structure of the NCC includes State and Territory Appendices in Schedule 1 which nominate variations that apply within a specific jurisdiction. The intent was to ensure that all technical provisions relating to the NCC scope were included in the NCC, even if State or Territory variations could not be avoided. However, additional drivers and constraints are often included in other National or State and Territory legislation and policies. In some cases, local government legislation and policies may also apply additional or different constraints.

1.3 Design for the Entire Building Life Cycle

Whilst the scope of the NCC is focussed on the design and documentation stages for new building works it does not negate the need for consideration of the performance of the building and all elements of the fire safety strategy throughout the building life cycle - refer Figure 4.

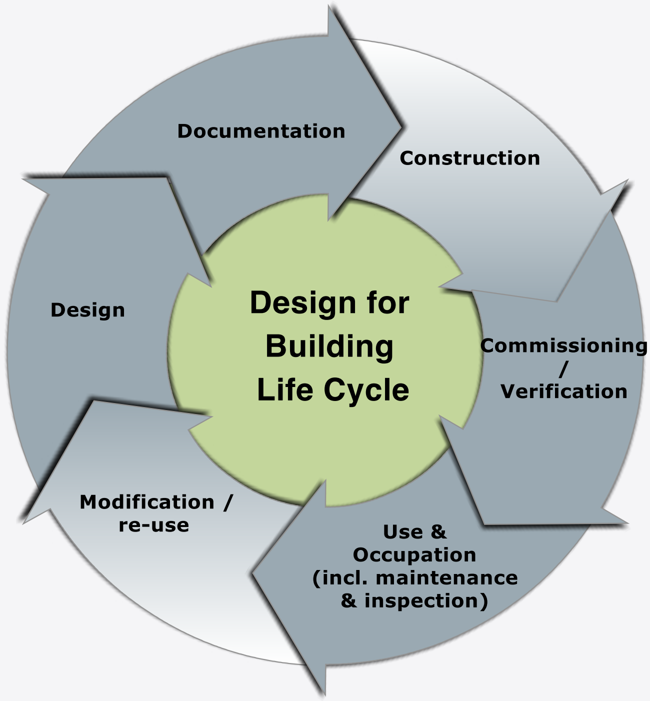


Figure 4: Schematic of typical building life cycle.

Typical examples of stages in the building life cycle where additional fire safety mitigation measures may apply are summarised below in relation to WHS Legislation which applies throughout the life of a building. Therefore, the design needs to account for construction, commissioning / verification, and expected use of a building once it is constructed and occupied including, amongst other things.

- installation and maintenance of fire safety measures without exposing people to undue risk. (e.g., provide safe access for installation of fire protection systems)
- avoiding specification of fire safety provisions which introduce additional hazards.
- addressing fire safety during construction and maintenance (whilst the NCC incorporates some fire safety provisions during the construction phase they do not fully address WHS obligations. Refer Wood Solutions Design Guide 20 - Fire Precautions During Construction of Large Buildings[8]
- facilities for subsequent safe inspection and testing of fire protection measures during occupation
- compatibility of the fire safety strategy with the Emergency Management Organisations (EMO) and related evacuation procedures and staff training post occupation.

The fire safety design does not stop once the fire safety strategy has been developed. The strategy needs to be translated into detailed design documentation and the process will typically involve a number of practitioners such as the following;

- Structural Engineers
- Fire Protection Engineers / Practitioner
- Services Engineers
- Building Designer
- Fire Safety Engineer (or other specialist practitioners for non-fire safety matters)
- EMO consultants / manages (if appointed)

Coordination with design team members throughout the development of the design documentation is critical to a good outcome.

The design also needs to consider the availability of fire protection systems and the availability of *Evidence of Suitability* which will need to be submitted to the *Appropriate Authority*. This is particularly important for some innovative *Performance Solutions* which may depart from the use of systems that comply with commonly applied standards.

1.4 Documentation and Control of Critical Information

Background to Documentation and Control of Critical Information

The Building Confidence Report [9] included recommendation 20 “that each jurisdiction requires that there be a comprehensive building manual for commercial buildings that should be lodged with building owners and be available for successive purchasers”. At the time of writing the ABCB had issued a discussion paper identifying potential options for implementation of the recommendation. Options identified included application of the recommendation to all Class 2 to 9 buildings and options placing responsibility on either the Building Surveyor or Building Owner for assembling a Building Manual.

As the provision of accurate and comprehensive information is critical to achieving and maintaining compliance and acceptable levels of safety through the life of a building, the process shown in Figure 5 is suggested, which integrates the design and documentation and construction processes with the development of a Building Manual. The Building Manual can be either an electronic folder as will be necessary for many major projects or may be a printed document. It is prepared initially by the design team, and then further developed during the construction process to address design changes and more detailed information about specific building products, equipment, and other safety measures. The manual should be treated in the same way as other *Evidence of Suitability* and submitted to the *Appropriate Authority* as part of the package of information on which fire safety compliance is verified. The process should be applied to all NCC and other safety provisions but focusses on fire safety here in line with the context of this Technical Design Guide.

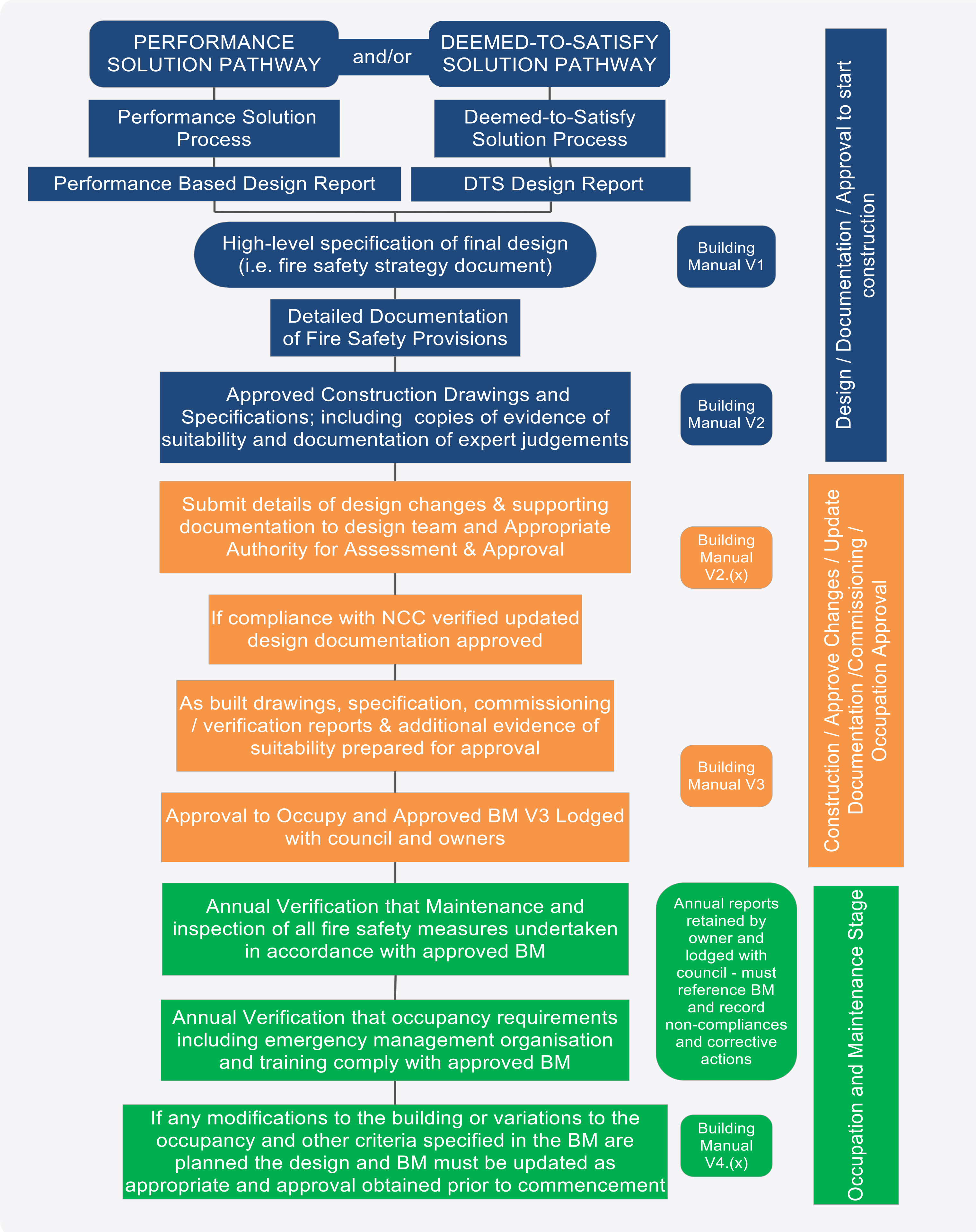


Figure 5: Documentation and Control of Critical Information.

Design and Documentation Prior to Construction

The processes stages shaded in blue relate to the design and documentation phases of the building life cycle and the building design team should take responsibility for the preparation of Versions 1 and 2 of the Building Manual. If a fire safety engineer is appointed, to a project it should be their responsibility to produce the fire safety parts of the Building Manual. Where the *DTS Solution* Pathway is adopted for simple projects a Fire Safety Engineer may not be appointed in which case the responsibility would generally fall on the lead designer (typically the architect) who would assemble the required documentation from other members of the design team or delegate the role to a member of the design team.

Whichever compliance pathway is adopted the initial outcome will be a high-level specification of the final design which is commonly referred to as the fire safety strategy. The strategy defines the combination of measures that are required to satisfy the fire safety objectives and includes physical and human measures.

i.e., the strategy should clearly identify constraints that apply to the use of the building, required fire safety measures including maintenance and inspection regimes, and requirements for the building Emergency Management Organisation including emergency procedures and training to facilitate an efficient and safe emergency evacuation of a building in conjunction with physical fire safety measures.

It is reasonably simple to provide this in the format of a Building Manual as Version 1 which should be submitted to the *Appropriate Authority* for approval before developing the Detailed Design Documentation. If a *Performance Solution* is adopted a complete copy of the performance-based design report should be included in an Appendix to the Manual. Further information relevant to the development of documentation at this stage is given in Chapter 5 Assessment Methods for Performance Solutions and Chapter 6 NCC Assessment Methods for DTS Solutions and Detailed Documentation of Fire Safety Provisions.

Construction, Commissioning and Verification Prior to Handover

It is acknowledged that in complex projects minor and sometimes major changes to a design may be required during the construction process. Minor changes to the design can have a significant impact on fire safety and therefore it is critical that the Building Manual and Performance Based Design Report are updated by the design team and approved by the *Appropriate Authority* to reflect any changes. These should be issued as revisions to Version 2 of the Manual with each revision being uniquely identified (i.e., V2.1, V2.2 etc)

Evidence of Suitability and other documentary evidence for the specific materials and systems used should be included in Appendices to the Manual. Further information relevant to the development of documentation at this stage is given in Chapter 6.

At the end of the construction phase the Building Manual should be updated to Version 3. The updated Version 3 should include as built drawings and updated supporting documentary evidence of compliance reflecting the actual construction including additional documents such as product technical statements and installation / inspection reports referring to the specific products supplied and installations. Any modifications to maintenance and inspection regimes should also be made at this stage.

The completed version 3 of the Building Manual and supporting documents such as "as built drawings" and *Evidence of Suitability* should be submitted to the *Appropriate Authority* to obtain approval to Occupy. Where progressive handovers occur progressive revisions of the Building Manual Version 3 can be issued at each handover stage.

The approved Building Manual and associated documents should be lodged with the building owners and retained by the *Appropriate Authority*. If processes are in place a copy should also be lodged with the relevant council so that it can be used as the basis for building inspections and audits and copies can be available for future occupants / owners if the originals are misplaced.

Use and Occupation including Maintenance and Inspection

The Building Manual includes requirements for annual maintenance and inspection of all fire safety measures and verification that occupancy requirements including emergency management organisation and training comply with intended designs.

Annual reports must be prepared that document inspection, maintenance and other compliance checks and record non-compliances, faults and corrective actions undertaken including the time taken for corrective actions to be implemented. These reports should also be retained by the owners and if processes / regulations are in place lodged with the relevant council / authority.

Modifications and Redevelopment

If any modifications to the building or variations to the occupancy and other criteria specified in the BM are planned the design and BM must be updated as appropriate and approval obtained prior to commencement. The modified design must be consolidated in a new version of the building manual (e.g., version 4) and the processes described in the above sections should be followed through the design, construction and occupancy phases of the redevelopment or refurbishment. A change in the Class of Building would also require modification of the Building Manual.

Lodgement, Format and Updating of the Manual

It is important that the Building Manuals are provided in a format that can be easily updated in the future using file formats that can be opened and edited without costly proprietary software or access to passwords. Locked PDF files or equivalent file types can also be provided to provide an historic record of a particular version of the document. Similarly, as built drawings and supporting documentation should use easily accessible file formats for future editing and viewing data.

A key element of the Building Manual is that it provides a consolidation of information required by the *Appropriate Authority* in order to issue a permit for commencement of construction and subsequently, on completion, to authorise occupation. When the building is occupied the Building Manual provides a useful tool for verification that the fire safety strategy is continuing to be implemented and maintained through the life of the building.

The above processes enable the building manual to be progressively developed through the construction and life of the building reducing the risk of key elements of the strategy being overlooked and reducing the need to rework existing analysis and undertake costly inspections.

Most States and Territories require design documents and annual statements to be lodged with local councils and the production of Building Manuals as outlined above is likely to simplify and standardised the lodgement process.

2

The National Construction Code (NCC)

2.1 General Structure of NCC

The NCC is Australia's primary set of technical design and construction provisions for buildings. It is a performance-based code which sets minimum levels for the safety, health, amenity, accessibility, and sustainability of certain buildings in order to satisfy relevant State and Territory building legislation.

A major advantage with the performance-based NCC is that there is no obligation to adopt any particular material, component, design factor or construction method. This provides flexibility to tailor a design to meet all the project drivers and constraints that may apply to a particular project in the most efficient manner.

For example, where project drivers require the use of a timber structure to address policies relating to sustainability, speed of construction and minimal impact on the surrounding community during construction, the use of timber is not prohibited by the NCC provided the relevant Performance Requirements are satisfied.

The NCC is published in three volumes.

NCC Volume One covers the design and construction of multi-residential, commercial, industrial, and public assembly buildings and some associated structures. This is the primary focus of this design guide.

NCC Volume Two predominately covers the design and construction of single dwellings and related structures. These are generally designed following the *Deemed-to-Satisfy* (*DTS Provisions*) and are addressed by other Design Guides but some information relating to *Evidence of Suitability* in this guide and others in the series may be relevant.

NCC Volume Three relates to the design, construction and maintenance of plumbing and drainage systems in new and existing buildings which lies outside the scope of this Design Guide.

The NCC Volume One contains amongst other things:

- *Governing Requirements*
- Technical Provisions
- State and Territory variations and additions.

The *Governing Requirements* provide the rules and instructions for using and complying with the NCC. They are vital in understanding how the technical requirements of the NCC should be applied to any particular situation.

The technical provisions are provided in Sections B to J of NCC Volume One and these Sections contain the relevant *Performance Requirements* and associated *Deemed-to-Satisfy Provisions*. The following definitions are provided in the NCC and are self-explanatory.

***Performance Requirement** means a requirement which states the level of performance which a **Performance Solution** or **Deemed-to-Satisfy Solution** must meet.*

Deemed-to-Satisfy Provisions** means provisions which are deemed to satisfy the **Performance Requirements

The majority of the fire safety content is included in Sections C, D and E and the application of these Sections to timber buildings or elements of a timber building is the primary focus of this design guide.

Section C Fire Resistance is of direct relevance to timber elements of construction and timber buildings, but Sections D and E also have relevance since the NCC applies a holistic approach to fire safety.

Additional fire safety content relating to specific applications is included in Sections G Ancillary Provisions and Section H Special use buildings and variations from the "standard" provisions in the body of the NCC are provided in State and Territory Appendices. These variations and additional provisions will not be specifically addressed in this Design Guide. Reference should be made to NCC Volume One for information on these sections and the State and Territory Appendices. Readers should note that it is necessary to check the applicability of other Sections of the NCC and State Appendices when involved in a fire safety design.

A series of schedules are included in the NCC which are referenced from the main body. These are:

- Schedule 1 State and Territory Appendices – identifying variations to the main body of the NCC
- Schedule 2 Abbreviations and Symbols – assists interpretation
- Schedule 3 Definitions – assists interpretation
- Schedule 4 Referenced Documents – assists usability
- Schedule 5 Fire–resistance of building elements – provisions for fire resistant elements of construction; of direct relevance to timber buildings
- Schedule 6 Fire hazard properties – provisions relating to the fire hazard of materials and assemblies such as wall and ceiling linings; of direct relevance to timber.
- Schedule 7 Fire Safety *Verification Method* – general comparative *Verification Method* which can be applied to timber buildings

2.2 Overview of Pathways for Demonstrating Compliance

The options for demonstrating compliance with the NCC are described in Part A2 Governing Requirements. Compliance is required with both:

- the *Governing Requirements* (Part A in NCC Volume One), **and**
- the *Performance Requirements*

As noted previously the *Governing Requirements* specify how the NCC should be used and address matters such as interpretation, reference documents, the acceptance of design and construction (including related *Evidence of Suitability* /documentation) in conjunction with the corresponding schedules

To comply with the NCC, buildings must satisfy the *Performance Requirements* in addition to the *Governing Requirements.*

Performance Requirements can be satisfied by:

a) following the *Performance Solution* pathway and demonstrating that all relevant *Performance Requirements* have been satisfied.

b) following the Deemed-to-Satisfy pathway which involves selecting an appropriate combination of *DTS Solutions* from the NCC (including materials, components, prescribed design, and construction methods), which are deemed to meet the *Performance Requirements*.

c) A combination of a) and b).

Note: Option c) is effectively a *Performance Solution* since the impact of variations from the *DTS Provisions* on the total fire safety system for the building need to be considered.

A *Performance Solution* is generally unique to each individual building and it is necessary to directly assess the *Performance Requirements*.

A *DTS Solution* comprises a combination of *DTS Provisions* which include materials, components, building layouts and configurations, and construction methods that, if used, are deemed to meet the *Performance Requirements*. In some instances, the NCC provides a choice of *DTS Provisions* that can be used to satisfy the *Performance Requirements*. To some extent this provides a level of flexibility for designers to select a combination of *DTS Provisions* to optimise a fire safety design in a manner that is consistent with all project drivers and constraints

One or more of the *Assessment Methods* specified in the NCC must be used to determine compliance with the *DTS Provisions* or the *Performance Requirements* depending on the pathway adopted. The procedures for demonstrating compliance using the DTS or Performance Pathways are compared in Figure 6.

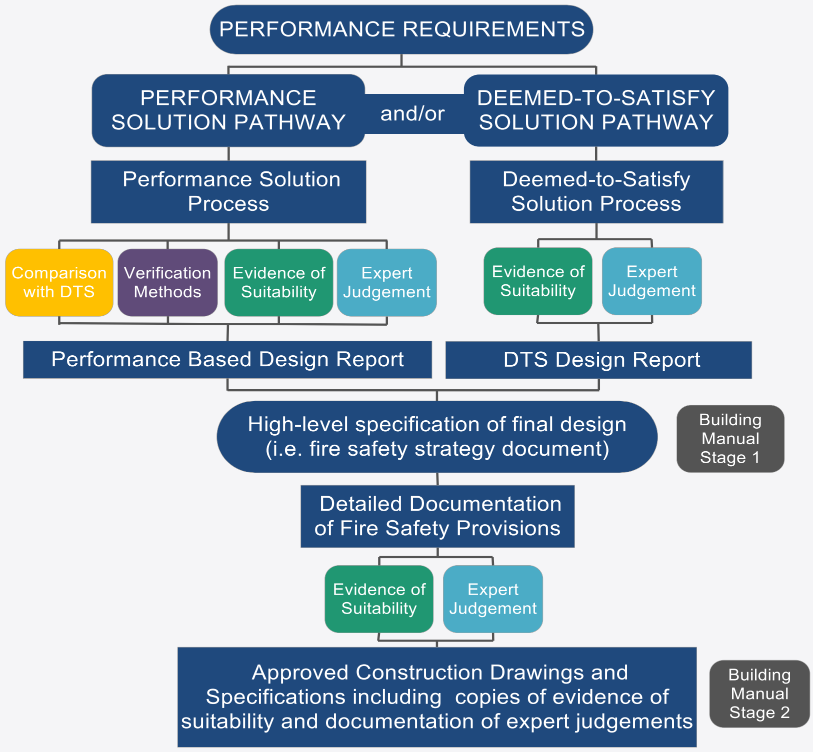


Figure 6 Overview of Procedure for Demonstrating Compliance with the NCC

The DTS and Performance Pathways follow different processes for the development and assessment of compliance of a high level specification of the fire safety design (the fire safety strategy).

At this stage, a high-level specification of the design in the form of a fire safety strategy should be submitted for approval to the *Appropriate Authority* before progressing to the detailed documentation of the fire safety provisions. The general NCC definition for the *Appropriate Authority* is provided below:

***Appropriate Authority** means the relevant authority with the statutory responsibility to determine the particular matter.*

In many instances the *Appropriate Authority* will be the appointed Building Surveyor or Certifier, but other entities can be nominated depending on the application and location.

Generally, the procedures for demonstrating compliance are similar for the *DTS Solution* and *Performance Solution* Pathways once an assessment of compliance of the *Performance Solution* against all relevant *Performance Requirements* has been undertaken or the *DTS Solution* has been selected.

If it is impractical to include specific *Evidence of Suitability* within the approved documentation at the design stage for a particular application, requirements for *Evidence of Suitability* should be specified within the approved design documentation. Once product selections have been made the required *Evidence of Suitability* shall be incorporated in the as built documentation and submitted to the *Appropriate Authority* for approval.

Note: Major design decisions should be made early in the design process to avoid unnecessary reworks of design documentation. This highlights the need for early involvement of a fire safety engineer and other critical stakeholders early in the process to ensure the fire safety design is compatible with other drivers and constraints.

2.3 Fire Safety Performance Requirements

The fire safety provisions make up a significant proportion of the content of NCC Volume One and the required performance is expressed through numerous *Performance Requirements* which tend to be interrelated encouraging the adoption of holistic approaches to fire safety designs.

This is best illustrated by considering two example *Performance Requirements*, CP1 and CP2, that are critical to the use of timber structural elements.

CP1 relates to structural stability during a fire and CP2 relates to the spread of fire. Fire safety strategies commonly address these *Performance Requirements* by specification of FRLs, provision of separation distances, specification of material fire hazard properties, non-combustibility (or fire-protected timber) and building geometry in combination with active fire safety systems, evacuation strategies and fire brigade intervention, as appropriate.

The fire safety *Performance Requirements* in NCC Volume One generally state what is to be achieved and provide a list of parameters that must be considered when determining compliance as shown in Figure 7. It can be seen that there are differences between CP1 and CP2 with respect to what is to be achieved but the parameters that have to be considered (within the dashed box) are similar.

Terms such as "to the degree necessary" are used in a number of the *Performance Requirements* of the NCC including CP1 and CP2 to provide flexibility when applying holistic approaches.

For example, timber structural elements can be used in some applications where non-combustible elements are commonly used as part of a *DTS Solution*, if other design features such as the use of fire-protected timber and / or automatic sprinkler systems are adopted to maintain structural stability appropriate to the listed parameters in CP1. These include parameters for consideration such as fire brigade intervention and any active fire safety systems installed in the building.

CP1 Structural stability during a fire

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 Spread of fire

(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*.

Figure 7 Comparison of Performance Requirements CP1 and CP2 *This figure is a derivative of the performance requirements CP1 and CP2 of the NCC provided by the Australian Building Codes Board © 2020. (https://ncc.abcb.gov.au/)*

The parameters for consideration comprise a mix of

- fire hazards,
- mitigation measures,
- risk exposure (people and property) e.g.;
  - number of occupants and vulnerability (function and use of the building)
  - other property at risk.

The fire related *Performance Requirements* in sections C to E of NCC Volume One can be consolidated into a matrix as shown in Figure 8. In all, there are 25 *Performance Requirements* (ignoring the *Performance Requirement* relating to fire precautions during construction) and fifteen parameters for consideration. The filled circles in Figure 8 represent parameters specifically referenced in the *Performance Requirements* and the open circles the parameters that are inferred by the context of the *Performance Requirement*. Some of the nominated *Performance Requirements* such as DP2, DP4, and DP6 are not specific to fire emergencies and may also apply to general usage and other emergencies. The fire safety analysis should consider these *Performance Requirements* as appropriate to the fire safety design, but additional analysis may be required for other emergencies and general safety within the building.

Figure 8 highlights the significant inter relationships between the fire safety *Performance Requirements* and in most cases holistic approaches need to be adopted to assess *Performance Solutions*.

Performance Requirement	Parameters for Consideration														
	Function or use of the building	Fire load	Potential fire intensity;	Fire hazard;	Height of the building / num. of storeys	Its proximity to other property	Any active fire safety systems	Size of any fire compartment / floor area	Fire brigade intervention	Other elements they support	Evacuation time	Number, mobility / occupant charact.	Travel distance	Exit above or below ground	Fire Safety System
CP1 Structural stability during a fire	●	●	●	●	●	●	●	●	●	●	●	○	○		○
CP2 Spread of fire	●	●	●	●	●	●	●	●	●	●	○	○	○		○
CP3 Spread of fire and smoke in health and res. care	○	○	○	○			○				○				
CP4 Safe conditions for evacuation	●						●				●	●	○		○
CP5 Behaviour of concrete external walls in a fire		○	○	○	○										
CP6 Fire protection of service equipment				○											
CP7 Fire protection of emergency equipment	○	○	○	○			○								
CP8 Fire protection of openings and penetrations	○	○	○	○	○	○	○	○	○	○	○				
CP9 Fire brigade access	●	●	●	●			●	●							
DP2 Safe movement to and within a building											○	○	○		
DP4 Exits	●			●							○	●	●	●	
DP5 Fire-isolated exits	●			●					●						●
DP6 Paths of travel to exits	●										○	●			
DP7 Evacuation lifts	●			●							○	●	●		●
EP1.1 Fire hose reels	●			●				●							●
EP1.2 Fire extinguishers	●			●											●
EP1.3 Fire hydrants				●				●	●						
EP1.4 Automatic fire suppression systems	●			●	●			●							
EP1.6 Fire control centres	●				●			●							
EP2.1 Automatic warning for sleeping occupants					○										
EP2.2 Safe evacuation routes	●	●	●	●			●		●		○	●	●		
EP3.2 Emergency lifts					○										
EP4.1 Visibility in an emergency	●							●					●		
EP4.2 Identification of exits								○				○	○		
EP4.3 Emergency warning and intercom systems	●				●			●							

Figure 8: Matrix of Performance Requirements and Parameters for Consideration.
This figure is a derivative of Table 7.1 Handbook - Fire Safety Verification Method provided by the Australian Building Codes Board © 2020. (https://ncc.abcb.gov.au/sites/default/files/resources/2020//Handbook_Fire_Safety_Verification_Method.pdf)

This has been recognised in CV4 - Fire Safety *Verification Method* which requires a holistic comparative approach to fire safety design. The assessment process also requires consideration of any relevant *Performance Requirements* in other sections of the NCC. For example, consideration of *Performance Requirement* BP1.1 Structural Reliability is necessary in many applications where CP1 is relevant.

Note: At the time of writing the *Performance Requirements* are expressed in qualitative terms which can lead to significant variations in interpretation of terms such as "to the degree necessary". However, the fire safety *Performance Requirements* are programmed for quantification in the 2022 edition with a draft for comment being released in May 2021 that effectively:

- consolidates the *Performance Requirements* into a life safety *Performance Requirement* and a property protection *Performance Requirement*.
- provides quantified risk-based criteria against which designs can be assessed reducing the subjectivity associated with determining compliance with *Performance Requirements*
- maintains a similar list of parameters for consideration.

2.4 Performance Solution Assessment Process for the Fire Safety Strategy

A Performance Solution complies with the NCC if it is demonstrated that the solution:

- Complies with all relevant *Performance Requirements or,*
- Is at least equivalent to the *Performance Requirements*

using one or more of the following A*ssessment Methods* are used;

- Comparison with the *Deemed-to-Satisfy Provisions*
- *Verification Methods*
- *Evidence of Suitability*
- *Expert Judgement*

and

if an absolute approach rather than comparison to a DTS Solution is adopted; the relevant *Performance Requirement*(s) are identified as follows:

- Relevant *Performance Requirements* from the Section or Part of the NCC to which the Performance Solution applies.
- *Performance Requirements* from other Sections or Part of the NCC that are relevant to any aspects of the *Performance Solution* proposed or that are affected by the application of the *Performance Solution*

Performance Solutions relating to fire safety State and Territory fire safety regulations generally require *Evidence of Suitability* in the form of a report from a professional fire safety engineer in addition to any other requirements of the NCC. This is consistent with NCC A5.2 *Evidence of Suitability* -Clause 1(e) which states:

> (e) A certificate or report from a professional engineer or other appropriately qualified person that -
>
> (i) certifies that a material, product, form of construction or design fulfils specific requirements of the BCA; and
>
> (ii) sets out the basis on which it is given and the extent to which relevant standards, specifications, rules, codes of practice or other publications have been relied upon to demonstrate it fulfils specific requirements of the BCA.

It therefore follows that the primary *Assessment Method* comprises *Evidence of Suitability* in the form of a report from a professional engineer. However, such assessments commonly apply more than one *Assessment Method* and different categories of *Evidence of Suitability*.

Note: National and State based accreditation of fire safety engineers is available. When relying on a certificate or report from a fire engineer it is prudent to check the credentials of the relevant engineer and recognition of the accreditation within the State or Territory in which the building works is to be undertaken. Legislation within a State or Territory often includes requirements for insurance of some practitioners.

Required Process for Demonstrating Compliance with of a Performance Solution

In July 2021, Clause A2.2(4) formally took effect, which specifies a step-by-step process which must be undertaken when developing and demonstrating compliance of a *Performance Solution*. It is to be used in conjunction with relevant Assessment Methods.

This process will ultimately result in a report from a professional engineer as the primary *Evidence of Suitability* for a *Performance Solution* but in most instances, it will be supplemented by other *Assessment Methods* described in the following sub-sections.

The step-by-step process in centred around the Performance-based Design Brief (PBDB) which is similar to the approach specified in the International Fire Engineering Guidelines (published by the ABCB in 2005) and has been applied extensively for *Performance Solutions* relating to fire safety in Australia.

Note: Some existing documents relating to fire safety *Performance Solutions* use terms such as Fire Engineering Brief (FEB) rather than the more general term Performance-based Design Brief (PBDB) which was introduced into the NCC so that the process is not specific to fire safety.

This process confirms the need for a formal report to be issued confirming compliance with the NCC.

The four steps are summarised below.

Prepare a Performance-based Design Brief (PBDB)

A PBDB is a documented process that derives a proposed *Performance Solution* (e.g., a fire safety strategy) and defines methods of analysis, associated inputs, and acceptance criteria. The scope and content of a PBDB will depend on the scope and complexity of the proposed solution. Its purpose is to set down the basis, as discussed and usually agreed by the relevant stakeholders, on which the analysis of the proposed building and its Performance Solution will be undertaken. The main PBDB activities are summarised in the chart below:

Generally, key stakeholders in a *Performance Solution* include:

- building owner or owner's representative
- builder or project manager
- relevant design process practitioners such as
  - architects
  - engineers (structural, hydraulic, fire safety, civil etc.)
  - design specialists (ESD, HVAC etc.)
  - building design professionals
  - trade practitioners
- *Appropriate Authority*, e.g., building surveyors and certifiers
- other relevant agencies related to *Performance Solution*
  - health
  - environment
  - fire safety (e.g., fire brigades)
  - infrastructure (water, sewerage, and stormwater)
- representatives of any other relevant party.

At the end of the PBDB process, the proposed fire safety strategy should be clearly defined such that all the relevant stakeholders have a clear expectation of the likely fire safety performance of the building and clearly understand their obligations in relation to the building project and subsequently through the building lifecycle.

Carry Out Analysis

Given that each Performance Solution is unique, each proposal will require an analysis / assessment specific to the solution being considered and other relevant attributes of the building.

The methods of analysis should therefore be agreed with the stakeholders and fully documented during the PBDB stage together with required inputs, outputs, and acceptance criteria. The methods of analysis and acceptance criteria must be consistent with one or more of the NCC *Assessment Methods* and address all relevant parameters nominated in the relevant *Performance Requirements*.

Evaluate Results

The results from the analysis should be compared to the acceptance criteria. If the acceptance criteria are not satisfied the proposed *Performance Solution* may require revision and depending on the changes to the design, the methods of analysis may also need adjustment. The PBDB will need to be revised accordingly and agreed with the relevant stakeholders prior to further analysis.

Prepare Final Report

Clause A2.2(4) of the NCC requires the following information to be included in the final report.

- all relevant *Performance Requirements* and/or *Deemed-to-Satisfy* Provisions
- identification of all *Assessment Methods* used; and
- details of the PBDB, Analysis and Evaluation of results; and
- confirmation that the relevant *Performance Requirement* have been met and
- details of conditions or limitations, if any exist, regarding the *Performance Solution*.

Note: Although not explicitly stated in clause A2.2, it is necessary for the final report to include, or cross reference, a detailed specification of the fire safety strategy which has been assessed for compliance with the NCC. This could be in the form of the section of a Building Manual addressing fire safety.

Whilst it is necessary for the fire safety strategy to be defined in order to undertake the assessment of a *Performance Solution* it is critical that the strategy is adequately documented to avoid key components, conditions or limitations being overlooked which could compromise the design. This documentation should not just be limited to a specification of physical fire safety measures and the building layout but should also address matters such as:

- evacuation strategies and the related requirements for an emergency management organisation and occupant training.
- installation, commissioning, and maintenance of equipment.
- expectations relating to fire brigade intervention.
- other critical conditions, limitations, and design features such as assumed occupant characteristics.

2.5 Deemed-to-Satisfy Solution Process

For a DTS Solution only *Evidence of Suitability* and *Expert Judgement* are applicable.

Design using *DTS Solutions* requires selection of an appropriate combination of DTS Provisions.

For more complex buildings the number of combinations of DTS Provisions can be large. Under these circumstances applying a simplified PBDB process to identify the most appropriate combination of *DTS Provisions* that is consistent with other stakeholder drivers and constraints can be beneficial.

This could be integrated into the initial design brief stage of a project if members of the design team have been appointed.

At the end of this process a DTS Design Report can be prepared which;

- clearly defines the fire safety strategy
- identifies all relevant *Deemed-to-Satisfy Provisions* (i.e., selected DTS options)
- identifies *Assessment Methods* for the *DTS Solutions* and
- confirms that the relevant *Performance Requirement* can be met through compliance with the relevant *DTS Provisions*
- details of conditions or limitations, if any exist, regarding the *DTS Solution*.

Similar to a *Performance Solution*, the document should not be limited to physical fire safety measures but should also address matters such as:

- evacuation strategies and the related requirements for an emergency management organisation and occupant training
- installation, commissioning, and maintenance of equipment.
- expectations relating to fire brigade intervention
- other critical conditions, limitations, and design features

2.6 Assessment Methods

The following definition of *Assessment Method* is provided in the NCC:

Assessment Method means a method that can be used for determining that a Performance Solution or Deemed-to- Satisfy Solution complies with the Performance Requirements.

The NCC groups *Assessment Methods* into four categories as shown in Table 1. One or a combination of these *Assessment Methods* may be adopted to assess compliance with the NCC in conjunction with other procedures specified in the *Governing Requirements*.

Table 1: Summary of NCC Assessment Methods.

Assessment Method	Applicability
Evidence of Suitability	Applies to performance and DTS Solutions
Expert Judgement	Applies to performance and DTS Solutions
Comparison with the Deemed-to Satisfy-Provisions	Applies only to Performance Solutions
Verification Methods	Applies only to Performance Solutions

A brief overview of each of the *Assessment Methods* follows. Further information on the general application of the various *Assessment Methods* is provided on the ABCB website which can be accessed from the following link. ***Australian Building Codes Board (abcb.gov.au)*** Application of the Assessment Methods to Timber Buildings is addressed in Chapter 6.

Comparison with DTS Solution

This *Assessment Method* involves a comparative analysis to demonstrate that a *Performance Solution* is better than, or at least equivalent to, the *Deemed-to-Satisfy Provisions*. The NCC definition for equivalent is:

Equivalent means equivalent to the level of health, safety and amenity provided by the Deemed-to-Satisfy Provisions.

To carry out this comparison, the applicable *Deemed-to-Satisfy Provision(s)*, and *Performance Solution* both need to be subject to the same level of analysis using the same methodology. This provides the building designer and Appropriate Authority with a defined benchmark or level for the *Deemed-to-Satisfy Provision* and the *Performance Solution*.

Following a comparative method determines whether the *Performance Solution* provides the same level of health, safety, amenity, or sustainability as using a *Deemed-to-Satisfy Solution*. If it is found that the *Performance Solution* is equal to or better than the *Deemed-to-Satisfy Provision*, then the *Performance Solution* proposal satisfies the NCC *Performance Requirements*.

The comparative Assessment Method is the basis for NCC *Verification Method* CV4 - Fire Safety *Verification Method* (FSVM), which provides guidance amongst other things in relation to the range of fire scenarios that must be compared. *Verification Method* CV 4 / DV4 / EV1.1, the fire safety *Verification Method* is discussed in more detail in Section 5.3.

Verification Methods

Verification Methods are tests, inspections, calculations, or other methods providing a means for demonstrating a *Performance Solution* complies with the relevant *Performance Requirements*. Some *Verification Methods* are prescribed within the NCC and may take a number of forms but generally include a quantifiable benchmark or predetermined acceptance criteria that the solution must achieve.

It is permitted to use *Verification Methods* not prescribed within the NCC; however there must be agreement with the *Appropriate Authority* and other relevant stakeholders that the *Verification Method* is acceptable. This can be incorporated within the PBDB process. Parts C to E include the following *Verification Methods* that may have direct relevance to the fire safety of timber buildings.

CV1 Fire spread between buildings on adjoining allotments
CV2 Fire spread between buildings on the same allotment
CV3 Fire spread via external walls
CV4 / DV4 / EV1.1 Fire Safety *Verification Method*
DV2 Access to and within a building
These *Verification Methods* and their application to timber buildings are discussed further in Chapter 5

Expert Judgement

The NCC definition of *Expert Judgement* is provided in the following text box:

> ***Expert Judgement** means the judgement of an expert who has the qualifications and experience to determine whether a **Performance Solution** or **Deemed-to-Satisfy Solution** complies with the Performance Requirements.*
>
> *Explanatory Information: Contemporary and relevant qualifications and/or experience are necessary to determine whether a **Performance Solution** complies with the **Performance Requirements**. The level of qualification and/or experience may differ depending on the complexity of the proposal and the requirements of the regulatory authority. Practitioners should seek advice from the authority having jurisdiction or **Appropriate Authority** for clarification as to what will be accepted.*

It is frequently necessary to make judgements when determining compliance with the NCC and particularly when determining compliance with qualitative *Performance Requirements*. Even when other *Assessment Methods* are being applied it is still often necessary to make judgements with respect to inputs and acceptance criteria.

Note: In engineering disciplines the term engineering judgement is commonly used when making decisions or judgements rather than expert judgment. The process may be formal, intuitive, or deliberate or, in most cases, a combination of the three.

Different types of experts may need to be registered with State and Territory accreditation bodies, registrars or nominated national accreditation bodies.

In general, in the field of fire safety, a professional fire safety engineer is required to carry out the *Performance Solution* process which includes;

- Preparing the PBDB in conjunction with relevant stakeholders
- Undertaking the analysis
- Evaluating the results
- Preparing a final report determining compliance and defining the fire safety strategy

As a professional fire safety engineer (registered with a professional body and / or the relevant State or Territory) a practitioner would meet the general requirements for qualifications and experience to determine compliance and may be expected to have the competence to make more routine engineering judgements associated with undertaking a fire safety engineering analysis and evaluating the results.

Note: What is legally defined as an expert will differ for individual States and Territories.

As indicated in the Explanatory information provided in the NCC the qualifications and experience required for a particular project differ depending on the complexity of the proposal and requirements of the *Appropriate Authority*.

Ultimately, it is the role of the *Appropriate Authority* to determine whether a particular person undertaking an *Expert Judgement* is considered an expert. Each situation is different, so the capacity of the expert (practitioner) to make appropriate judgements must be individually assessed on a project-by-project basis.

Therefore, it is important before appointing a fire safety engineer to clarify the extent of their expertise and likely acceptability to the *Appropriate Authority* and other relevant stakeholders.

If significant *Expert Judgements* are required beyond that associated with routine fire safety engineering design practice, extra confidence can be obtain to some extent if the PBDB stakeholders include people with expertise in the field of fire safety and/or an independent Peer Review is commissioned. Techniques such as sensitivity analyses can be used to further inform expert / engineering judgements.

Note that typically under State and Territory laws, the *Appropriate Authority* cannot be part of the design process as they are to independently assess the proposal. Therefore, they cannot provide an *Expert Judgement* for a matter they are considering for approval.

Evidence of Suitability

The NCC provides numerous options under the *Assessment Method* category of *Evidence of Suitability* which can be selected depending on the application. Many of the *Evidence of Suitability Assessment Methods* are most suited to the assessment for compliance with the NCC of the detailed documentation (drawings and specifications) and therefore can apply to both *Performance Solutions* and *DTS Solutions*.

Note: When defining the fire safety strategy for a ***Performance Solution*** *it is important that the required performance of components of the fire safety strategy are specified in a form that can be readily developed into detailed design documentation by a competent practitioner and subsequently assessed for compliance. Required maintenance procedures should also be identified. This can be achieved by, as far as practical, referencing appropriate Australian and International Standards and nominating required* ***Evidence of Suitability*** *in a form that is consistent with DTS Solutions. Such approaches reduce the risks of misunderstandings and errors being introduced during the development of design documentation and construction of the building and facilitate the maintenance of the systems and components throughout the building life.*

There are specific requirements for *Evidence of Suitability* for the following fire related properties of a material or systems which will be addressed specifically in Chapter 6 since they are directly relevant to timber:

- Fire-resistance of building elements
- Fire-hazard properties
- Resistance to the Incipient Spread of Fire

In addition, the following options are available for other applications:

- A current CodeMark Australia or CodeMark Certificate of Conformity.
- A current Certificate of Accreditation.
- A current certificate, other than those described above, issued by a certification body stating that the properties and performance of a material, product, form of construction or design fulfil specific requirements of the BCA (NCC Volumes One and Two).
- A report issued by an Accredited Testing Laboratory that -
  - demonstrates that a material, product, or form of construction fulfils specific requirements of the BCA (NCC Volumes One and Two); and
  - sets out the tests the material, product or form of construction has been subjected to and the results of those tests and any other relevant information that has been relied upon to demonstrate it fulfils specific requirements of the BCA (NCC Volumes One and Two).
- A certificate or report from a professional engineer or other appropriately qualified person that -
  - certifies that a material, product, form of construction or design fulfils specific requirements of the BCA (NCC Volumes One and Two); and
  - sets out the basis on which it is given and the extent to which relevant standards, specifications, rules, codes of practice or other publications have been relied upon to demonstrate it fulfils specific requirements of the BCA (NCC Volumes One and Two).
- Another form of documentary evidence, such as but not limited to a Product Technical Statement, that -
  - demonstrates that a material, product, form of construction or design fulfils specific requirements of the BCA (NCC Volumes One and Two); and
  - sets out the basis on which it is given and the extent to which relevant standards, specifications, rules, codes of practice or other publications have been relied upon to demonstrate it fulfils specific requirements of the BCA (NCC Volumes One and Two).

The NCC defines a Product Technical Statement as:

a form of documentary evidence stating that the properties and performance of a building material, product or form of construction fulfil specific requirements of the NCC, and describes -

(a) the application and intended use of the building material, product, or form of construction: and

(b) how the use of the building material, product or form of construction complies with the requirements of the NCC Volume One and Volume Two; and

(c) any limitations and conditions of the use of the building material, product, or form of construction relevant to (b).

*Note: Seeking a Product Technical Statement in addition to, for example, relevant test reports from an **Accredited Testing Laboratory** can provide added confidence that the test reports provided relate to the specific products provided the Product Technical Statement references the test reports. It is strongly recommended not to solely rely on product technical statements.*

3

Structural Timber Building NCC Compliance Pathway Options

3.1 Overview of Fire Properties of Timber

This brief overview of the fire properties of timber in this section provides a simple explanation of the engineering principles underpinning the compliance pathway options for the fire safety of timber buildings.

In common with all structural building materials, timber construction has advantages that can be optimised and disadvantages that can be managed to achieve an acceptable level of safety.

When exposed to a severe fire, timber will decompose releasing volatiles, but a char layer is formed which 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. There will be a heat affected zone between the char and unaffected timber where some pyrolysis may occur, and the mechanical properties of the timber will be modified. The process is depicted in the simplified schematic shown in Figure 9.

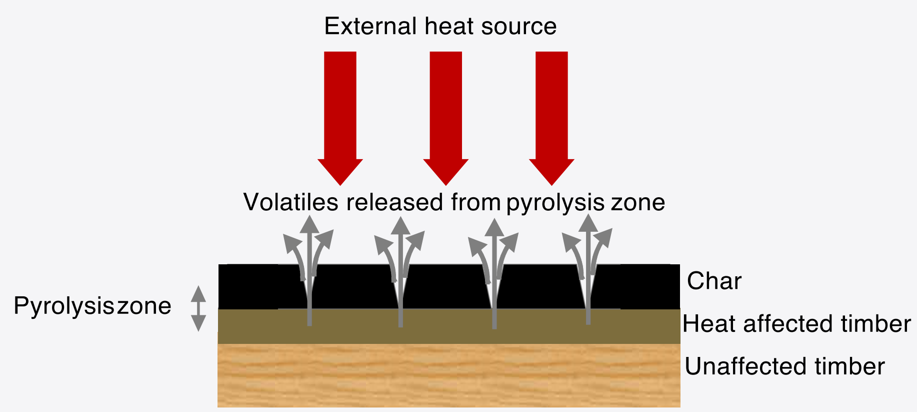


Figure 9: Schematic showing a section through a Burning Section of Timber.

Some of the more critical considerations for the fire safety design of timber buildings can be summarised as follows:

- Timber is combustible and may therefore;
  - contribute to the fire load within an enclosure unless it is fully encapsulated.
  - influence fire growth when used as an exposed timber wall and ceiling linings or the surfaces of elements of construction such a cross laminated timber are exposed. Most structural timbers and wood products with a density above 400kg/m^3 are expected to be classified as Group 3 in accordance with AS 5637 [10] but with appropriate fire retardant treatments this can be improved to Groups 1 or 2.
  - Combustion may continue after burnout of the contents under certain circumstances further reducing the loadbearing capacity of an element or sub-assembly.
- As timber burns it produces a protective char insulating the core of the element and reducing the burning rate.
  - Elements of construction with large cross-sections (Massive timber) can therefore achieve high inherent fire resistance levels without additional fire protection and
  - Protected massive elements are less susceptible to sudden structural failures if a protection system fails due to the high inherent fire resistance of the timber element.
- The coefficient of thermal expansion of timber is relatively low compared to other common building materials. This tends to reduce deflections and induced stresses due to differential heating during fire scenarios.

3.2 NCC Compliance Pathways for Timber Buildings.

The NCC *DTS Provisions* apply a simple risk-based approach based on the rise in storeys to determine the minimum Type of fire resisting construction and also apply area / volume constraints as shown in Table 2.

Table 2: Types of Construction Required by NCC Vol. One.

Rise in storeys or effective height	Multi-residential		Office	Retail	Car Park/ Storage	Factory / Laboratory	Hospitals / Assembly / Schools
	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

Type A construction is the most fire resisting form of construction and the general DTS solutions for Type A construction impose severe limitations on the use of timber through the additional prescription of masonry and concrete construction and non-combustibility for some structural elements required to achieve a prescribed Fire Resistance Level (FRL). Type B construction, whilst not requiring as high FRLs as Type A construction, applies similar constraints to the use of timber.

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.

However, the NCC does include some DTS pathways that permit the more general use of structural timber members under specific circumstances where Type A and B construction is required. Table 3 summarises these compliance pathways. The cells highlighted in green indicate available DTS options which are described in the following sections. The blue cells indicate applications where there are no DTS solutions prescribed in the NCC and therefore a *Performance Solution* (PS) is the only pathway for compliance.

Table 3: NCC Compliance Pathways for Timber Buildings.

Rise in storeys or effective height	Multi-residential		Office	Retail	Car Park/ Storage	Factory / Laboratory	Hospitals / Assembly / Schools
	Class 2	Class 3	Class 5	Class 6	Class 7	Class 8	Class 9
Effective height (EH) > than 25m	PS	PS	PS	PS	PS	PS	PS
8 (EH<25)	FPT	FPT	FPT	FPT	FPT	FPT	FPT
7 (EH<25)	FPT	FPT	FPT	FPT	FPT	FPT	FPT
6 (EH<25)	FPT	FPT	FPT	FPT	FPT	FPT	FPT
5 (EH<25)	FPT	FPT	FPT	FPT	FPT	FPT	FPT
4	FPT / TFC	FPT / TFC	FPT	FPT	FPT	FPT	FPT
3	TFC	TFC	FPT	FPT	FPT	FPT	FPT
2	TFC	TFC	Type C	Type C	Type C	Type C	FPT
1	Type C	Type C	Type C	Type C	Type C	Type C	Type C

It should be noted that:

- a *Performance Solution* can be applied to any height and Class of building and may consider an innovative structural fire safety design or consider non-structural fire safety provisions that vary from the DTS solutions. In either case it is necessary to ensure the fire safety system as a whole satisfies the required levels of safety.
- The Fire-Protected Timber (FPT) pathway can be selected as an alternative to Type C construction or the timber frame concession (TFC) pathways for low rise buildings.

Type C Construction

Type C construction is generally restricted to buildings with a rise in storeys of 1 or 2 depending on the building Class as indicated in Table 3. Lower area limits also apply to Type C construction compared to Type A and B construction.

Due to the relatively low height and area restrictions applied to Type C buildings the DTS requirements for the fire performance of structural elements are substantially relaxed from the general requirements that apply to Type A and B construction.

For example:

- The number of elements requiring to be of fire-resistant construction (required to achieve FRLs) is reduced.
- Lower FRLs for external walls which are located more than 1.5 metres from a fire-source feature are specified and only requiring a maximum FRL of 90 minutes for any criterion.
- Most building elements in a building required to be of Type C construction are not required to be non-combustible, or of concrete or masonry.

There are few restrictions on the use of timber structural members and exposed structural elements can be used subject to compliance with *Fire-hazard Properties*, fire resistance requirements and other DTS requirements.

The following WoodSolutions Design Guides provide detailed information relating to compliance using the Type C construction DTS compliance option.

- WoodSolutions Technical Design Guide 2 Timber-framed Construction for Multi-residential Buildings – under revision at the time of preparation of this Design Guide
- WoodSolutions Technical Design Guide 3 Timber Framed Construction for Commercial Buildings Classes 5, 6, 9a & 9b

Timber Framed Concession (TFC)

The NCC DTS requirements in Specification C1.1 for Type A and B construction have general provisions that require elements such as external walls, common and non-loadbearing fire-resisting wall and shafts to be built from non-combustible materials and loadbearing internal and fire walls to be built from concrete or masonry which restrict the use of timber structural elements.

However, the NCC Specification C1.1 Clauses 3.10 and 4.3 provide concessions permitting the use of timber framed construction subject to specific conditions.

In summary the concessions:

- permit timber framed construction to be used for Class 2 and 3 buildings (multi-residential buildings) having a rise in storeys up to 3 provided other materials used in the wall construction such as thermal insulation satisfy the NCC DTS requirements relating to non-combustible construction.
- allow the use of timber framed construction to be extended to buildings with a rise in storeys of four if
  - the lowest *storey* is used solely for the purpose of parking motor vehicles or for some other ancillary purpose; and
  - the lowest *storey* is constructed of concrete or masonry including the floor between it and the Class2 or 3 part of the building above; and
  - the lowest *storey* and the *storey* above are separated by construction having an FRL of not less than 90/90/90 with no openings or penetrations that would reduce the *fire-resisting* performance of that construction except that a doorway in that construction may be protected by a –/60/30 *self-closing* fire door.

i.e., 3 levels of timber framed construction on top and fire separated from a one storey concrete structure used for ancillary purposes.

- if a sprinkler system complying with Specification E1.5 is provided (other than a FPAA 101D or FPAA 101 H system), the FRLs are reduced for a number of elements of construction.

The concessions are reproduced in full in Appendix B.

The concession was originally introduced for Class 2 buildings, based on extensive research and quantitative risk assessments undertaken at Victoria University of Technology and described by Beck[11] performed in the early 1990s with supplementary testing and literature reviews undertaken to justify the extension to Class 3 buildings in 2011[12].

The following WoodSolutions Design Guide provides detailed information relating to compliance using the Timber-framed Concession DTS compliance option.

- WoodSolutions Technical Design Guide 2 Timber-framed Construction for Multi-residential Buildings (Low-rise Class 2 & 3) – under revision at the time of preparation of this Design Guide.

Fire-protected timber (FPT)

The elements of the fire-protected timber concession are shown in Figure 10. The following definitions from the NCC are needed to interpret and apply the concession.

***Fire-protected Timber** means fire-resisting timber building elements that comply with Volume One Specification C1.13a*

***Massive timber** means an element not less than 75 mm thick as measured in each direction formed from solid and laminated timber.*

The definition for *Massive timber* was introduced to allow relaxations to the Fire-protected Timber requirements for timber elements with large cross-sections that do not include cavities to account for the removal of the risk of cavity fires and the beneficial effects of timber with larger cross-sections.

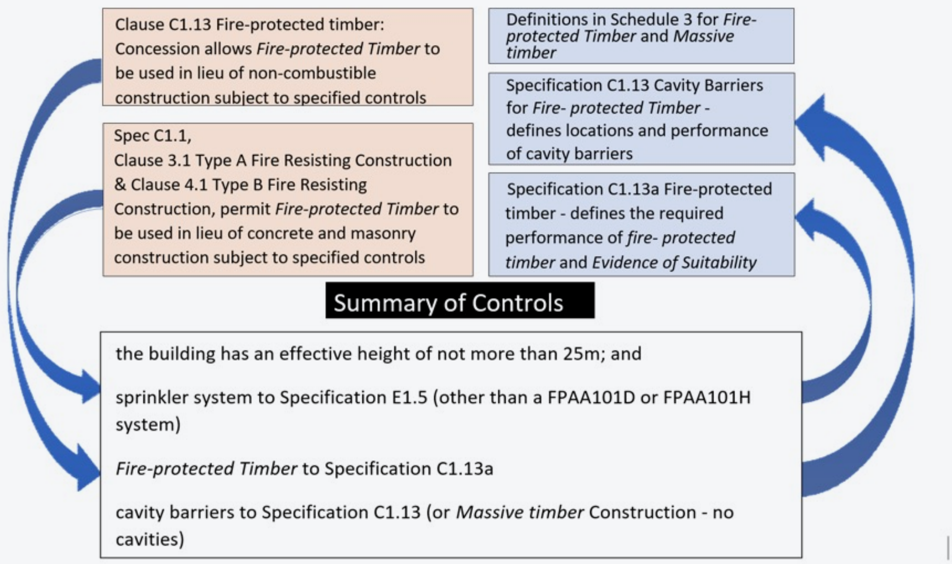


Figure 10: Fire Protected Timber Concession Structure.

The fire-protected timber concession is primarily triggered by clause C1.13 which allows *Fire-protected Timber* to be used in lieu of non-combustible construction, but it is supplemented with content in Specification C1.1 Clauses 3.1 and 4.1 which also allow the use of fire protected timber in lieu of concrete or masonry construction.

Clause C1.13 and Specification C1.1 Clauses 3.1 and 4.1 restrict the use of *Fire-protected Timber* construction under the DTS pathway to buildings with an effective height of not more than 25m and apply the following additional controls;

- a sprinkler system to Specification E1.5 (other than a FPAA101D or FPAA101H system) must be provided
- *Fire-protected Timber* must comply with Specification C1.13a
- cavity barriers must be provided in accordance with Specification C1.13 and
- if cavity insulation is provided it must be non-combustible.

The general requirements for *Fire-protected Timber* construction are provided in Specification C1.13a clause 2.1 which is presented in the text box below:

2.1 General requirements

(a) Fire-protected Timber must -

(i) utilise a non-combustible ***fire-protective covering*** *fixed in accordance with the system requirements to achieve an FRL not less than that required for the building element; and*

(ii) have a ***non-combustible fire-protective covering*** *fixed in accordance with system requirements -*

(A) to achieve a Resistance to the ***Incipient Spread of Fire*** *of not less than 45 minutes when tested in accordance with -*

(aa) for horizontal elements — Section 4 of AS 1530.4; and

(bb) for other elements - the relevant test procedures from Section 4 of AS 1530.4 applied to the element lining; or

(B) which consists of not less than 2 layers of 13 mm thick, fire-protective grade plasterboard.

(b) For the purposes of (a), the ***non-combustible fire-protective covering*** *provided under (a)(ii) may form all or part of the* ***non-combustible fire-protective covering*** *provided under (a)(i).*

Further details relating to appropriate *Evidence of Suitability* is discussed in Section 6

As noted above the general requirements can be relaxed under certain circumstances if *Massive timber* elements are employed. The *Massive timber* requirements for Fire Protected Timber construction are provided in Specification C1.13a clause 2.2 which is presented in the text box below:

2.2 Massive timber

(a) ***Fire-protected timber****, where the timber is* ***massive timber****, need not comply with Clause 2.1 if the fire-protected timber -*

(i) utilises a ***non-combustible fire-protective covering*** *fixed in accordance with system requirements to achieve an FRL not less than that* ***required*** *for the building element; and*

(ii) has a ***non-combustible fire-protective covering*** *fixed in accordance with system requirements -*

(A) so as the temperature at the interface between the protection system and the timber does not exceed 300°C during a fire resistance test performed in accordance with Clause 3 for the application and periods listed in Table 1; or

(B) not less than that specified by Table 1; and

(iii) has either -

(A) any cavity -

(aa) between the surface of the timber and the fire-protective covering; or

(bb) between timber elements within the fire-protective covering,

filled with ***non-combustible insulation****; or*

(B) no cavity -

(aa) between the surface of the timber and the ***fire-protective covering****; or*

(bb) between timber members within the ***fire-protective covering****.*

(b) For the purposes of (a), the non-combustible ***fire-protective covering*** *provided under (a)(ii) may form all or part of the* ***non-combustible fire-protective covering*** *provided under (a)(i).*

Refer to Table 4 for a copy of Table 1 from specification C1.13a Performance Solutions for high-rise buildings

Table 4: Specification C1.13a Table 1 Interface temperature and minimum fire protective grade plasterboard thickness from the NCC.

Application	Time – without timber interface exceeding 300°C (mins)	Minimum thickness of fire-grade plasterboard (mm)
Inside a fire-isolated stairway or lift shaft	20	13
External walls within 1 m of an allotment boundary or 2 m of a building on the same allotment	45	2 x 13
All other applications	30	16

Further details relating to appropriate *Evidence of Suitability* including determination of interface temperatures are provided in Section 6.

The *Fire-protected Timber* concession was originally introduced for Class 2, 3 and 5 buildings in 2016 and extended to other classes in 2019. The following WoodSolutions Design Guides provide detailed information relating to compliance using the Fire-protected Timber Option.

- WoodSolutions Technical Design Guide 37R [4] - Mid-rise Multi-residential buildings (Class 2 and 3)
- WoodSolutions Technical Design Guide 37C [5] - Mid-rise Commercial and Education buildings (Class 5,6,7,8 and 9b,including Class 4 parts)
- Wood Solutions Technical Design Guide 37H [6] - Mid-rise health-care buildings Class 9a and Class 9c

Details of the supporting analysis have been provided in WoodSolutions Technical Design Guide 38 Fire Safety Design of Mid-rise Timber Buildings - Basis for the 2016 changes to the National Construction Code. [13] to provide background information when developing *Performance Solutions*.

Miscellaneous applications

The previous sections outlined the primary DTS Options for Timber Structures in the NCC however there are applications where timber construction can be used for specific structural and non-structural applications in accordance with the NCC DTS Provisions for applications where the NCC permits combustible structural elements or materials and does not restrict materials to concrete or masonry.

Typical examples include wall and ceiling lining materials and timber flooring where *Evidence of Suitability* can be provided to show that the required *Fire-hazard Properties* have been satisfied.

In relation to timber structures a typical example is the DTS solution for Class 9c aged care accommodation which adopted a sprinkler and smoke detection based strategy enabling some relaxations with respect to FRLs, compartmentation and requirements for non-combustibility. Details of this approach are provided in

- WoodSolutions Technical Design Guide 42 [7]. - Timber Aged Care Buildings (Class 9c).

For these miscellaneous applications in particular interpretations of the NCC should be checked with the *Appropriate Authority* early in the design process to ensure any restrictions on the use of timber have not been overlooked.

3.4 Performance Solutions Compliance Options

In theory there are no constraints, if the *Performance Solution* pathway is adopted, to demonstrate compliance of timber structures with the NCC irrespective of the height of a building, provided it can be demonstrated that the relevant *Performance Requirements* have been satisfied.

However, as building heights increase the time required for evacuation increases considerably and the timing and effectiveness of fire brigade intervention is reduced. To manage the impact of these effects and take account of the larger populations within high-rise building that are at risk if structural collapse occurs, it is generally necessary to increase the reliability of the performance of the structure when exposed to fire conditions, in addition to requiring automatic fire suppression systems.

Performance Solutions for high-rise buildings

A common approach for high-rise buildings is to enhance the *Fire-protected timber* construction provisions by increasing the efficacy of the protection system (e.g., increasing the thickness of materials protecting a timber element) and reliability (improved fixing methods, supervision, and quality assurance systems) in addition to the provision of automatic sprinkler systems potentially with enhancements as the risk increases with increasing height. To differentiate these enhancements from the DTS fire protected timber systems that apply to DTS mid-rise building solutions the term "encapsulated timber" is commonly adopted.

Exposed structural timber

It is a common wish to expose some structural timber elements as an architectural statement.

Exposure of timber structural elements can:

- impact the rate of growth of a fire
- increase the effective fire load (potentially increasing the fire severity) and
- increase the risk of structural collapse due to continuing smouldering combustion reducing the residual cross-section of timber fixings and performance of connections

It should be noted that most structural timbers and wood products with a density above 400kg/m^3 are expected to be classified as Group 3 in accordance with AS 5637 [10] but with appropriate fire retardant treatments this can be improved to Group 2 and therefore exposed timber linings are permitted under current *DTS Provisions* for some applications. Where this applies the impact of growth rate and to some extent an allowance for an increase in fire severity may have been incorporated within the DTS solutions, but this will need to be adequately demonstrated when assessing the *Performance Solution*.

The risk of continuing flaming or smouldering combustion potentially leading to collapse is specific to timber structural elements and will need to be considered as part of a *Performance Solution* when timber is ignited during a fire scenario. Based on the work of Crielaard [14] heat fluxes above 5 to 6kW/m^2 are required for smouldering combustion to continue. From the AFAC Fire brigade Intervention Model Manual [15], Fire Brigade personnel with full PPE and BA would be able to withstand an incident heat flux of 3kW/m^2 for 10 minutes and 4-4.5kW/m^2 for approx.1 minute. The timing (or heat flux levels) at which smouldering combustion is assumed to cease and / or the fire brigade could start suppressing any residual smouldering combustion should be determined during the PBDB process when considering the subject building. For small enclosures suppression activities could commence from outside the enclosure and therefore the timing is less sensitive to the heat flux within the fire enclosure.

4

Design Process for Fire Resistant Structural Elements and Barriers

4.1 Overview of Design Process of Structural Elements and Barriers

The process for the design of structural elements and barriers to resist exposure to fire involves the three stages listed below:

- Derivation of the Design Fire,
- Heat transfer Analysis (including assessment of insulation performance for barrier systems), and
- Structural Analysis (including an assessment of the formation of gaps and openings for assessment of integrity of barriers).

A flow chart showing the key stages of the process is shown in Figure 11 based on the flowchart from NCC Fire Safety Verification Method (FSVM) Handbook Annex [16] which was derived from a chart originally prepared for structural design by Buchanan[17].

The three stages can be consolidated in some applications depending on the adopted methods of analysis and selected compliance pathways.

For example, the NCC DTS solutions generally specify a nominal design fire based on the standard heating regime of AS 1530.4 with the performance of elements of construction expressed in terms of fire resistance levels (FRLs.)

The NCC defines the Fire-resistance level (FRL) as the grading periods in minutes determined in accordance with Schedule 5 of the NCC, for the following criteria—

(a) ***structural adequacy****; and*

(b) ***integrity****; and*

(c) ***insulation****,*

and expressed in that order.

A dash means that there is no requirement for that criterion. For example, 90/–/– means there i s no requirement for an FRL for integrity and insulation, and –/–/– means there is no requirement for an FRL.

The required period of exposure to the standard heating regime is varied to address different fire exposure conditions with heat transfer and functional performance being evaluated by subjecting a representative specimen to a fire resistance test or other methods permitted by the NCC such as calculation in accordance with AS 1720.4 [18]

The Design Guide: Structural Fire Safety, produced by the Conceil International du Bâtiment (CIB W14) [19], identified three types of Heat Exposure Models (Design Fires) and three types of Structural Response Models based on single elements, sub-assemblies or entire structures. The matrix produced by CIB W14 has been compacted and cross referenced with NCC performance pathways and required *Evidence of Suitability* as shown in Table 5.

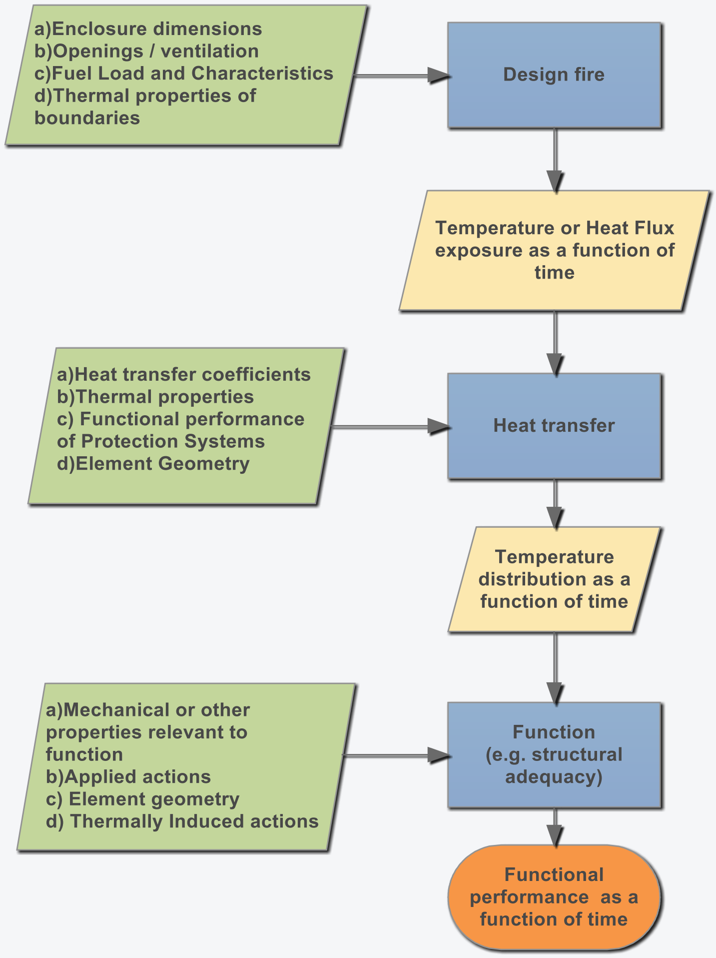


Figure 11: Design Process for Fire Resistant Structural Elements and Barrier Systems.

Table 5: Performance Pathways and Evidence of Suitability compared to Design Fire and Extent of Structural Analyses.

Compliance Pathway	Design fire	Extent of Structural Analysis	Evidence of Suitability
Deemed-to-Satisfy	AS 1530.4 standard heating regime	- Generally individual elements - Occasionally sub-assemblies	NCC Schedule 5 (test or assessment from an Accredited Testing Laboratory (ATL) or permitted calculations)
Simple Time Equivalence *Performance Solution*[1]	Equivalence to AS 1530.4 standard heating regime	- Generally individual elements - Occasionally sub-assemblies	NCC A2.2- demonstration of compliance / *Evidence of Suitability* [2] and NCC Schedule 5 (test, assessment from an ATL or permitted calculations)
More Complex *Performance Solution*	Parametric curve or other theoretical or experimentally derived design fire	Varies with application, could be single elements, sub-assemblies, or whole structure	NCC A2.2- demonstration of compliance / *Evidence of Suitability* [2] and NCC Schedule 5 (test, assessment from an ATL, permitted calculations or natural fire tests, or alternative heating regime tests

*Note 1 Time equivalence is the simplest **Performance Solution** option and relates the expected real fire exposure to a time of exposure to the standard (AS 1530.4) heating regime. Where timber elements are exposed or may become exposed the fire load must be adjusted to take account of the additional contribution from the timber.*

*Note 2 **Evidence of Suitability** will also need to include a report from a competent person (e.g. a professional engineer) assessing compliance of the fire safety strategy with the relevant **Performance Requirements** where the **Performance Solution** Pathway is followed. Additional **Evidence of Suitability** will also be required to verify the performance of key structural elements / components.*

The appropriate methods of analysis should be selected based on the compliance pathway adopted. The extent of analysis required for the design fire(s), heat transfer and structure (or other required function) must be determined having regard to the requirements of the specific project and agreed by the relevant stakeholders as part of the Performance Based Design Brief (PBDB) process.

4.2 Design Fires

Deriving Fire Exposure

If a DTS pathway is followed, the performance of structural elements exposed to enclosure fires is generally expressed in terms of the period of time the element continues to support the applied load when exposed to the standard heating regime of AS 1530.4 as noted in Table 5. If the element also serves a fire separating function integrity and insulation criteria are also applied. The standard heating regime of AS 1530.4 has common origins and is similar to many other international fire resistance test method heating regimes such as ISO 834 [20]

Note: The term nominal heating regime is sometimes used as an alternative to standard heating regime.

The duration for which the performance criteria are required to be satisfied when exposed to the standard heating regime can be varied to account for the differences between the expected thermal exposure (gas temperature and radiant incident heat flux together with appropriate boundary conditions) applicable to the application and exposure to the standard test conditions. The AS 1530.4 standard heating regime is compared to average enclosure fire temperatures from a typical natural fire test using timber cribs as the fire load in Figure 12 highlighting the differences in the enclosure temperatures.

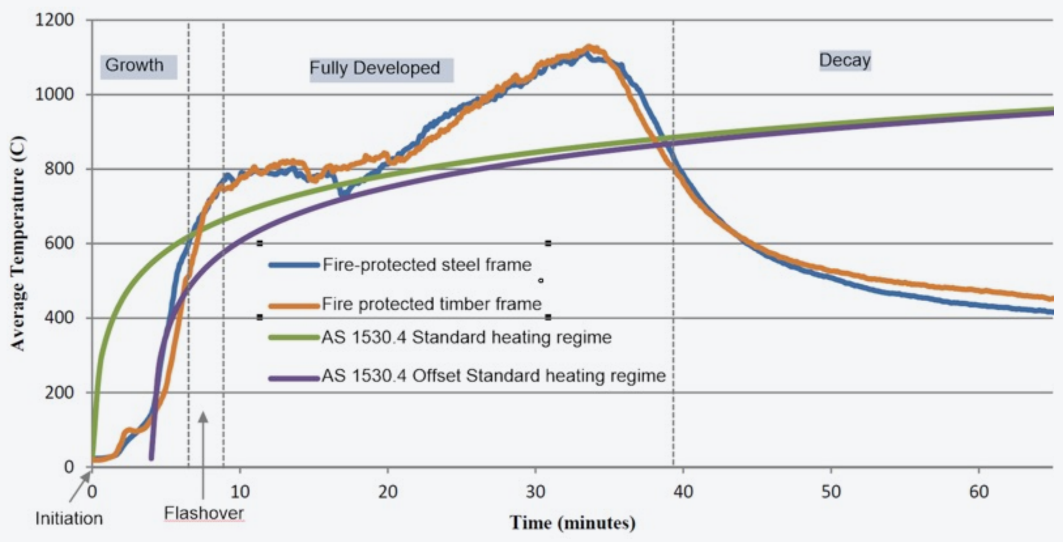


Figure 12: Average enclosure temperatures compared to the AS 1530.4 heating regime for timber and steel wall and ceiling members protected by fire grade plasterboard.

If a performance pathway is followed, a design fire or a number of design fires representing a distribution of potential critical fire scenarios should be defined that take account of the fire dynamics including potential contributions from timber structural elements if exposed (i.e. unprotected timber elements).

If unprotected timber elements are exposed, the rate of pyrolysis and combustion processes are dependent upon the thermal exposure and environmental exposure (oxygen content) which may also need to be taken account. Schmid [21, 22] suggested the introduction of the term "fire exposure" which accounts for both thermal and environmental exposures. Fire exposure is discussed further in Design Guide 18.

It is common to subdivide an enclosure fire into the following four stages when undertaking fire engineering analyses:

- Incipient
- Growth
- Fully Developed
- Decay

In some applications, it may be necessary to extend the analysis and consider a cooling phase if the behaviour of elements of construction, after extinction of the contents (moveable fire load) and combustible elements, is to be considered. Typically, this may be necessary where degradation of elements of construction occurs after extinction of the contents due to thermal inertia, degradation on cooling (e.g. Dimia et al [23]) and / or combustion of elements of construction (e.g. McGregor [24]).

A schematic example of an enclosure fire is shown in Figure 13.

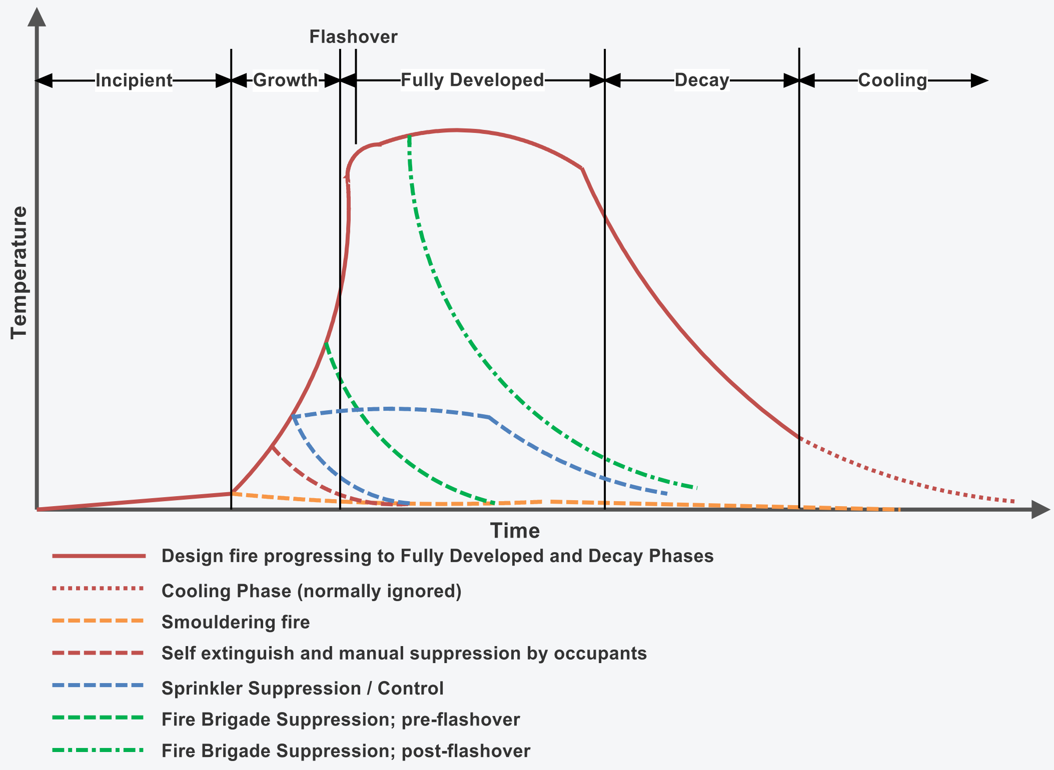


Figure 13: Design Fire Stages and Interventions.

The incipient phase is commonly used for evaluation of a smouldering fire (SF); for example, the SF scenarios in sleeping areas in the NCC Fire Safety *Verification Method* (FSVM)[25]. The exposure of elements of construction during the incipient phase is expected to be negligible and can generally be ignored when modelling the impact of a design fire on an element of construction. However, when undertaking a holistic analysis of a structure, and considering matters such as occupant evacuation and fire brigade intervention, it may be appropriate to determine the probability and timing of detection and alarm during the incipient phase. The incipient phase may also require investigation if there is a risk for fire initiation and spread through concealed spaces.

After the incipient stage, a fire may transition to a flaming fire corresponding to the fire growth stage. The characteristics of the *Design Fire* during this stage can be determined from one or more of the following sources if a performance pathway is followed:

- Full scale enclosure fire tests /experiments
- Furniture calorimeter tests
- Cone calorimeter tests
- Statistical data / fire incidents
- Calculation / fire modelling

Depending on the methods of analysis and *Design Fires* adopted, it may be necessary to quantify the exposure of an element (and its response) to a growing fire although in many calculation methods or fire models the growth phase may be incorporated within a fully developed fire model.

Also shown in Figure 13 are typical interventions by occupants, fire brigade and automatic suppression / control systems (e.g., sprinklers) that can modify the exposure of the element of construction.

Identifying Fire Scenarios for Analysis

There are many fire scenarios / fire scenario clusters that are unlikely to compromise the performance of a structure or structural elements and therefore the required analysis can reasonably be restricted to a limited number of fire scenarios / fire scenario clusters.

For example, in a small or medium sized enclosure a fully developed fire is required in order to challenge the structural adequacy of the elements of construction or structure as a whole but only a proportion of fires will progress to flashover.

Typically, once ignition occurs:

- a fire may simply smoulder and self-extinguish or be suppressed by the occupants
- progress to a small flaming fire but not spread beyond the object first ignited or be suppressed by the occupants
- if an automatic suppression system is provided and operates successfully the fire may be suppressed
- if the fire growth rate is relatively slow and the fire brigade are notified relatively quickly the fire may be manually suppressed before flashover occurs.

If probabilities are determined for these events, it is possible to derive the probability of a flashover fire occurring by means of a simple event tree similar to that shown in Figure 14.

The event tree can be extended to consider the effectiveness of structural fire protection if provided and fire brigade intervention. When defining the effectiveness of structural fire protection systems, it is important to consider the probability and consequences of gross defects such as the omission of protection or substitution with materials providing little protection. These types of gross defects are not adequately modelled by a simple assumption such as a normal distribution but can be addressed either by means of a separate branch in the event tree (scenario cluster) as in the example above or a two-peak distribution as applied in the analysis supporting the mid-rise DTS fire protected timber building solutions in the NCC which is described in more detail in WoodSolutions Design Guide 38 [13].

The probability of fire brigade suppression activities being successful after flashover can be introduced to the event tree. If fire brigade intervention is unsuccessful and the element cannot withstand burnout structural failure will occur.

Generally, with respect to safety of occupants and fire fighters the scenarios involving a gross defect will result in a premature and potentially unexpected failure presenting the greatest hazard to occupants although the probability of occurrence may be low.

To help interpret the results objectively it is generally necessary to undertake a risk assessment so that both the frequency and outcomes can be considered.

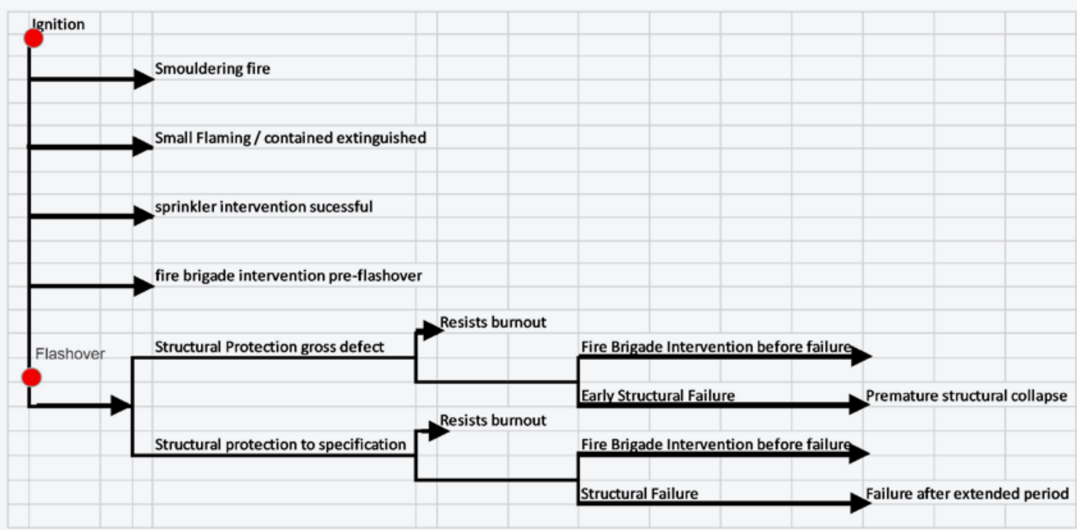


Figure 14: Simple event tree structure for evaluation of structural performance when exposed to fire.

4.3 Heat Transfer

This process uses the fire exposure determined during the first stage to derive a temperature distribution with respect to time for individual elements, sub-assemblies or the whole structure depending upon the design approach adopted.

There are a range of methods available for determining temperature distributions including:

- empirical correlations for simple lumped thermal mass or char rate calculations
- finite element analysis
- application of data from standard fire tests or natural fire experiments.

In some applications char oxidation, char layer contraction and delamination may need to be considered.

The methods should be appropriate to the application under consideration and appropriate validation of the methods undertaken.

Variations in material properties and quality of installations should be accounted for. In some scenarios this may require consideration of major variations representing unauthorised or incorrect substitution of materials or use of inappropriate fixings, for example, to determine the robustness of the overall fire safety strategy. This can be addressed through the consideration of fire scenario clusters as described in Section 4.2.

Further details of heat transfer analysis for timber elements and *Fire-protected Timber* elements exposed to fully developed fires are provided in Technical Design Guide 18.

4.4 Functional Performance

There are a range of methods that can be used to check the functional performance of individual elements, sub-assemblies or the whole structure. In addition to determination of the time to structural failure for elements providing a separating function, criteria relating to integrity and insulation may also apply.

Analysis options include:

- simple hand calculations using prescribed critical temperatures or char rates and effective residual section for timber elements (e.g. AS 1720.4[26] method)
- finite element modelling or calculations using material properties
- application of data from standard fire tests or natural fire experiments

Where necessary, the interaction of elements of construction, including thermally induced deflections and stresses should be evaluated to determine if the structure has adequate robustness. Detailed modelling of the whole or major parts of the structure under a range of fire scenarios may be required.

Note: Timber tends to be less prone to thermally induced actions during a fire due to its low coefficient of thermal expansion relative to other common building materials, but care should be taken with detailing timber construction to avoid generating significant thermally induced stresses or where this cannot be avoided the analysis should account for the thermally induced actions.

In some cases, it may be appropriate to either directly apply experimental / fire test data where the heating regime and applied loads are representative of the case under consideration, or the impact of variations can be predicted based on fire engineering principles.

Applied Loads for the Fire Limit State

The structural loading of elements of construction under fire limit state conditions is prescribed in AS 1170.0 [27] which requires the design actions (loads) for the fire limit state to be determined based on the following actions:

$G + \psi_l Q +$ (thermal actions arising from the fire) where:

G is the permanent action (dead load including self-weight)
Q is the imposed action (live load)
ψ_l is the long-term factor (0.4 for residential, offices, parking, and retail and 0.6 for storage and other occupancies).

Further details of determination of the functional performance of timber elements are provided in Technical Design Guide 18.

4.5 Determination of default loading for fire tests

It is common practice for test sponsors to nominate test loading for specimens when undertaking fire resistance tests on loadbearing elements of all types of material. In many cases the test loads are calculated using relevant structural design codes and characteristic material properties but the basis of the derivation of the test load is often not clearly stated in test reports other than to note the applied load was nominated by the test sponsor.

It is useful to express a fire test load (or design load capacity under fire conditions determined by calculation) in terms of the ratio of the fire test load to the design capacity of the member under "normal use (ambient) conditions" This load ratio can be used to compare loading levels simplifying the process of interpreting test results (*Evidence of Suitability*) for relevant structural design codes and the National Construction Code.

Design Codes for other structural materials such as AS4100 [28] use the ratio of design action on the member under design load for fire to the design capacity of the member at room temperature to determine load levels for testing and or analysis.

A similar approach can be adopted for timber elements but under Australian design codes (e.g.AS 1720.1 [29]) the design capacity of a member at room temperature varies with the load duration factor (k_1). This was identified by Nicholls [30] who observed that in order to compare load cases and determine load levels for fire testing, it was necessary to take into account the duration of load factor for strength (k_1) in addition to the load combinations required to be considered by AS/NZS 1170.0 [27]. The original approach proposed by Nicholls has been further developed and is described in this section.

To provide a benchmark that is independent of the load duration factor, the load duration independent design capacity R_b is determined by calculating the design capacity in accordance with AS 1720.1 at ambient conditions assuming $k_1 = 1$ which will be designated as the ***ambient benchmark design capacity***.

The action (or load) that can be resisted in the fire situation can be expressed as a proportion of the ambient benchmark design capacity and is represented by the symbol LR_{fb}. The appropriate value of LR_{fb} is now determined taking into account potential load combinations and the load duration factors given in AS 1720.1

Load Cases for Load Duration factors.

Table G1 from AS 1720.1-2010 [29] provides load duration factors for typical load combinations for the strength limit state. Table 6 is an extract from Table G1 of AS 1720.1 with wind and earthquake actions excluded.

Table 6: Load Duration factors For Typical Load Combinations for Strength Limit State from AS 1720.1 [29].

Type of load (action)	AS/NZS 1170.0 specified load combination*	Load duration factor	
		Solid Timber	Joints
Permanent action (dead load)	1.35 G	0.57	0.57
Permanent and short-term imposed actions	1.2 G +1.5 Q		
(a) Roof live load—Distributed		0.94	0.77
(b) Roof live load—Concentrated		0.97	0.86
(c) Floor live loads— Distributed		0.80	0.69
(d) Floor live loads— Concentrated		0.94	0.77
Permanent and long-term† imposed action	$1.2 G + 1.5 \psi_l Q$	0.57	0,57
Fire	$G + \psi_l Q$	0.94	0.77

** The notation used in this Table is drawn from AS/NZS 1170.0.*

† Long-term in this context is the terminology in AS/NZS 1170.0 for the quasi-permanent component of imposed action.

Determination of Default Fire Test Load Conditions

The derivation of default fire test load conditions has been demonstrated below.

The following cases will be considered:

Case	Description	Load combination	k_1
1	Permanent action (dead load)	1.35 G	0.57
2	Permanent and short term-imposed actions	1.2 G +1.5 Q	0.8 - 0.97
3	Permanent and long-term imposed action	1.2 G + 1.5 ψ_lQ	0.57
	Fire	G + ψ_lQ	0.94

ψ_l = 0.4 (from Table 4.1 of AS/NZS 1170.0:2002 [27] for residential, offices and retail buildings and 0.6 for other building uses).

AS 1720.1 requires member capacity for various design actions to be determined as follows and should be greater than the design action or applied load

$Rd = \Phi\, k_{mod}\, f'_o\, X \geq G + \psi_l Q$

Where:

R_d = the design capacity
Φ = capacity factors
k_{mod} = product of modification factors
$f'_o X$ = characteristic capacity appropriate to the action effect

Capacity factors and modification factors other than load duration factor (k_1) are generally the same for ambient temperature and fire design cases and will not therefore influence the load ratio LR_{fb}.

Therefore, the maximum capacity for fire for determining the LR_{fb}.ratio will be:

$(G + \psi_l Q)/k_1$, or

$(1+0.4\alpha)$ G/ 0.94, assuming k_1=0.94, ψ_l = 0.4 and α=Q/G

Case 1 Permanent action dead load only

The maximum design load under ambient conditions (R_b) occurs when:

$1.35G = R_b \times 0.57$
Therefore $R_b = 1.35G / 0.57 \approx 2.37G$
The maximum load condition under fire conditions = $(1+0.4\alpha)$ G/ 0.94
Therefore $LR_{fb} \approx (1+0.4\alpha) / 0.94/2.37 = (1+0.4\alpha) / 0.397$

The LR_{fb} ratio with the ratio of live to dead loads is plotted for a range of Q / G ratios in Figure 15.

Case 2 Permanent and short term-imposed actions

The maximum load condition under ambient conditions occur when:

$1.2\,G + 1.5\,Q = R_b \times 0.8$

If the ratio of Q/G = α

$(1.2+1.5\,\alpha)\, G = 0.8\, R_b$

Therefore $R_b = (1.2+1.5\,\alpha)\, G / 0.8$

$LR_{fb} = (1+0.4\,\alpha)\, G / 0.94\, ((1.2 +1.5\,\alpha)\, G / 0.8)$

$= 0.8\,(1+0.4\,\alpha) / 0.94\,(1.2+1.5\,\alpha)$

The LR_{fb} ratio with the ratio of live to dead loads is plotted for a range of Q / G ratios in Figure 15.

Case 3 Permanent and long-term imposed action

The maximum load condition under ambient conditions occur when:

$1.2\,G + 1.5 \times 0.4 \times Q = R_b \times 0.57$

If the ratio of Q/G = α

$(1.2+0.6\,\alpha)\, G = 0.57\, R_b$

Therefore $R_b = (1.2+0.6\,\alpha)\, G / 0.57$

$LR_{fb} = (1+0.4\,\alpha)\, G / 0.94\, ((1.2+0.6\,\alpha)\, G / 0.57)$

$= 0.57\,(1+0.4\,\alpha) / 0.94 / (1.2+0.6\,\alpha)$

The LR_{fb} ratio is plotted for a range of Q / G ratios in Figure 15

Critical Load Combinations

Typically, when undertaking a design for ambient temperatures the design capacity will be checked for the relevant cases which will typically include cases 1 to 3. For design at ambient temperatures the critical load case for determining the design capacity of a member will be the one that applies the greatest design action and hence load. The critical design case can vary with the ratio of live to dead load when each case is also divided by the k_1 value shown in Table 6 appropriate for that load case..

For all cases the structural loading for fire conditions is the same; i.e. $(1+ \psi_l \alpha)$ G, k_1=0.94

LR_{fb} is proportional to the ratio of imposed load when exposed to fire conditions (divided by k_1) over the design capacity or maximum applied design load under each of the ambient condition load cases (divided by k_1).

Therefore, the critical case for design at ambient temperatures, (i.e. the case that applies the greatest load under ambient conditions) will yield the lowest LR_{fb} ratio which is shown as the solid grey line in Figure 15.

This yields a maximum load ratio (LR_{fb}) of 0.494 which has been rounded to 0.5 to provide a maximum value for determination of fire test loads. Case 2 was also checked using a k_1 value for structural design of 0.97 in lieu of 0.8 which will not increase the minimum LR_{fb} above 0.494.

A LR_{fb} value of 0.5 will be conservative in many applications particularly where the sizing of structural elements is dominated by factors such as serviceability rather than load capacity. The option for test sponsors to specify other load levels for specific applications should therefore be retained but the LR_{fb} ratio should be clearly stated to avoid confusion.

Examples have been provided in Appendix C of two common end conditions to demonstrate the importance of clearly defining the end conditions to calculate the appropriate test load.

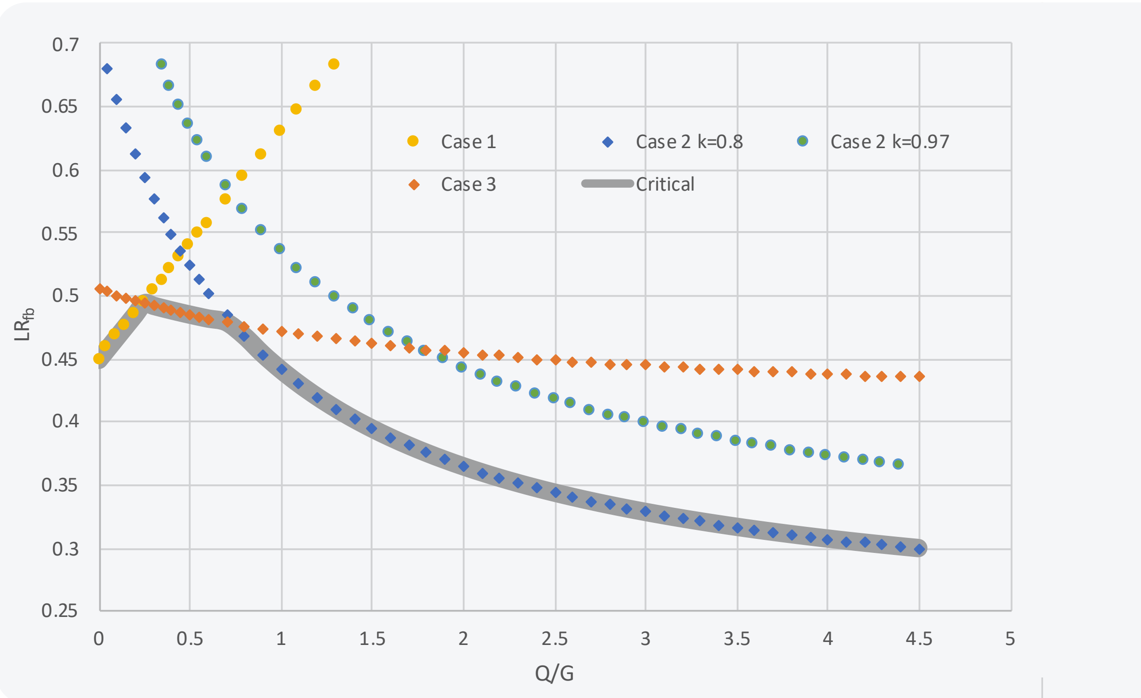


Figure 15: LR^{fb} ratio plotted against the ratio of live to dead loads (Q / G).

Default Load Ratio for Fire Testing

Where a fire test is being undertaken for general application, unless the design loads under fire conditions can be clearly defined, the following approach is recommended for structural elements

To provide a benchmark that is independent of the load duration factor, the load duration independent design capacity R_b is determined by calculating the design capacity in accordance with AS 1720.1 at ambient conditions assuming k_1 = 1 which will be designated as the ambient benchmark design capacity.

LR_{fb} is the ratio of design action or fire test load applied to the element to the ambient benchmark design capacity.

For general application of fire test data load-bearing elements should be fire tested at a load ratio (LR_{fb}) of at least 0.5

5

Assessment Methods for Performance Solutions

5.1 Fire Spread between Buildings

Performance Requirements and DTS Solution

The *Performance Requirement* that relates directly to fire spread is CP2 (see text box below for an extract from NCC Volume One: 2019) and sub-clause CP2(a)(iii), which has been highlighted in a bold font, specifically relates to fire spread between buildings:

CP2 Spread of fire

(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
***(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.

The above text is derived from performance requirement CP2 provided by the Australian Building Codes Board © 2020. The original content is provided in the NCC 2019 Ammendment 1

The development of a *Performance Solution* which impacts on the risk of fire spread between buildings is not straight forward because the nature of the hazard from buildings and vulnerability of buildings on the same or adjacent allotments may change independently from the subject building (the building for which the *Performance Solution* is being developed). For example, an adjacent allotment may be unoccupied when a *Performance Solution* is being verified but subsequently a new building may be built on the adjacent allotment.

It is therefore necessary to take account of potential developments within the allotment boundaries and on adjacent allotments. Various methods have been adopted internationally and all methods have their strengths and weaknesses.

In Australia this is addressed through the DTS pathway, by specification of non-combustible construction for external walls for high rise and medium buildings (Type A and Type B construction respectively) together with prescribed separation distances (from adjacent buildings on the same allotment and from allotment boundaries), limitations placed on unprotected openings in external walls supplemented by other general measures such as specification of automatic sprinklers in all buildings above 25m effective height.

Verification Methods CV1 and CV2

Verification Methods CV1 and CV2 provide a means of addressing the uncertainty regarding further developments if the performance pathway is followed. *Verification Methods* CV1 and CV2 place controls on the heat flux the subject building is permitted to impose on an adjacent building, as well as the heat flux that the subject building is required to resist from adjacent structures. To address potential hazards outside the subject building's allotment boundaries, heat flux limits are specified relative to the boundary position in Table CV1 in the NCC; whilst the limits relating to buildings on the same allotment are specified in Table CV2 of the NCC. For convenience Tables CV1 and CV2 have been consolidated in Table 7 below:

Table 7: Limiting Heat Fluxes for verifying Compliance with CP2(a) (iii) (consolidation of NCC Tables CV1 and CV2. *The original content was provided by the Australian Building Codes Board © 2020 from NCC 2019 Amendment 1*

Column 1	**Column 2**	**Column 3**
Distance from Boundary (m)	Distance between buildings on the same allotment (m)	Limiting heat flux(kW/m^2)
0	0	80
1	2	40
3	6	20
6	12	10

CV1 indicates compliance with CP2(a)(iii) has been verified when it is calculated that -

(a) a building will not cause heat flux in excess of those set out in Column 3 of Table 7 at the location on an adjoining property set out in Column 1; and

(b) when located at the distances from the allotment boundary set out in Column 1 of Table 7, a building is capable of withstanding the heat flux set out in Column 3 without ignition.

CV2 indicates compliance with CP2(a)(iii) to avoid the spread of fire between buildings on the same allotment has been verified when it is calculated that -

(a) a building is capable of withstanding, without ignition, the heat flux set out in Column 3 of Table 7 at the distance set out in Column 2 from a building on the same allotment; and

(b) a building will not cause heat flux in excess of those set out in Column 3 of Table 7 when the distance between the buildings on the same allotment is set out in Column 2.

The fire safety engineer still has to determine appropriate inputs which should be agreed with the *Appropriate Authority(ies)* and other relevant stakeholders on the PBDB team. Typical required inputs include:

- the size and intensity of the fire source from the subject building is required to calculate the incident heat flux on an adjacent building or allotment. This generally requires consideration of fire dynamics within the fire compartment, the effectiveness of compartmentation, and the additional exposure from a plume extending beyond the compartment together with fire propagation over the façade of the building if combustible cladding materials are used. If fire spread between floors occurs or other failures of internal compartmentation occur multiple fire sources may need to be considered.
- the likely exposure period and time to ignition when determining if ignition will occur when a building is exposed to the nominated incident heat fluxes. Above a critical heat flux of nominally 10-12.5kW/m^2, exposed timber products may ignite with the time to ignition varying with the incident heat flux, potential ignition sources and material properties of the target material.
- assessed levels of reliability of fire safety preventing fire spread between buildings. Acceptable probabilities of fire spread between buildings have been included as a metric in the draft quantification of the *Performance Requirements,* released for public comment in May 2021.

Note: Material properties and methods for predicting ignition times are available in Wood Solutions Technical Design Guide 18 - Fire Safe Design of Timber Structures - Methods of Analysis and Supporting Data (2021) and from the WoodSolutions website. Data sources and information relating to enclosure fire tests are also provided in Technical Design Guide 18.

Appendix C of AS 5113 [31] includes a test method that exposes external wall elements to radiant heat flux which can be used for the assessment of building to building fire spread.

When checking whether a subject building will cause heat fluxes greater than those listed in Column 3 of Table 7, the incident heat flux at each distance should be checked.

When checking whether a subject building can withstand the heat fluxes listed in Column 3 of Table 7, the distance from a boundary or adjacent building on the same allotment may lie between the nominated distances in columns 1 and 2. No guidance is provided within the NCC with respect to interpolation of values for buildings located at intermediate distances although various approaches have been suggested including:

- the use of a standardised heat source,
- simple linear interpolation, or
- conservatively rounding down the distance to the next value in Table 7.

If it is necessary to consider intermediate distances, the relevant fire safety engineer will need to justify the approach taken.

Where existing buildings are located close to the subject building, the analysis should also check the risks of fire spread to, or from, the subject building with respect to adjacent existing buildings since the existing buildings and separation distances may not comply with current NCC provisions.

5.2 Fire spread via external walls

Performance Requirements and DTS Solution

The Performance Requirement that relates directly to fire spread is CP2 with subclauses CP2(a)(iii) and CP2(b)(iv) having relevance to external walls. (Refer to the text box in Section 5.1 for an extract of CP2).

The NCC DTS pathway primarily addresses fire spread via external walls by means of the use of non-combustible materials and physical separation of openings within external walls using spandrel panels, horizontal projections, or separation distances to reduce the risk of a fire spreading between floors via an external fire plume for mid-rise and high rise buildings of Type A or B construction

Openings between the slab perimeter and curtain walling are also required to be fire protected to reduce the risk of early fire spread inside curtain walling.

Concessions allow the use of fire protected timber for external walls and relax the requirements for spandrel panels and horizontal projection provisions under the DTS pathway for some sprinkler protected buildings; but protection at the perimeter of the slab to the face of curtain walling is still required.

If the fire separation between levels of the building is insufficient and automatic sprinkler systems are not provided or are ineffective, external fire spread to an upper level can occur as shown in Figure 16. Without intervention, the secondary fire may develop to a fully developed fire and the process may be repeated leading to progressive fire spread to multiple floors. This process is sometimes referred to as leapfrogging.

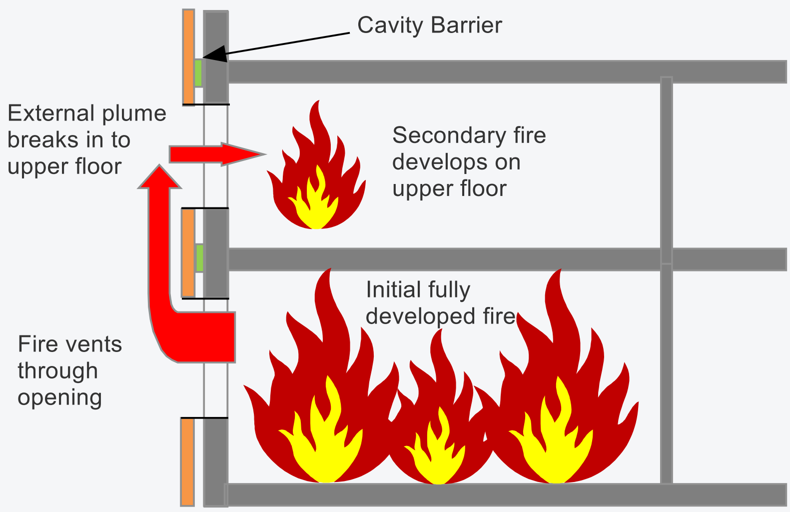


Figure 16: Fire Spread via a plume from a fully developed fire.

In configurations where the fire resistant floor slabs do not extended through the external wall, cavity barriers are required. If these cavity barriers are missing or faulty, fire and smoke spread to the level above can occur rapidly between the slab edge and external facade as shown in Figure 17.

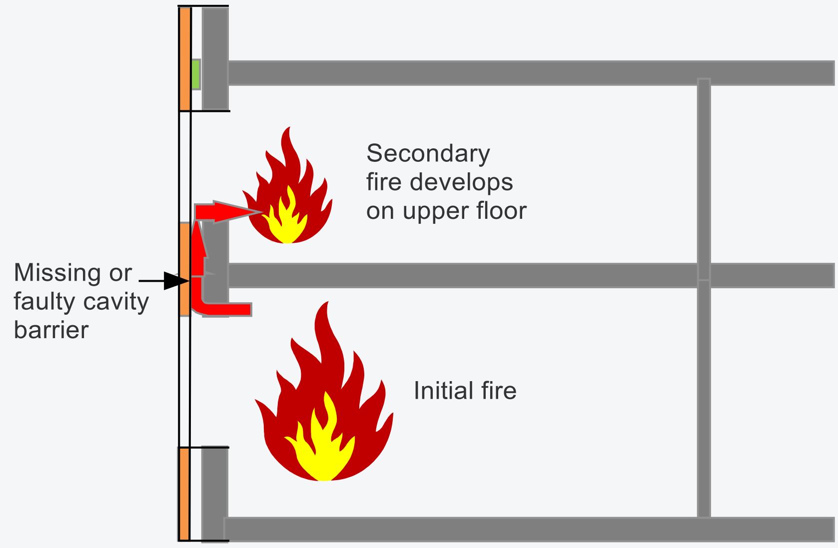


Figure 17: Fire spread path if fire protection at slab perimeter is inadequate.

Combustible External Walls and CV3

The risk of external fire spread can increase if combustible cladding systems are used without appropriate mitigation measures and this has been highlighted by many recent major fires involving combustible facades that facilitated rapid spread between floors of high-rise buildings.

For example, if high risk combinations of materials are used, rapid fire spread over large areas of a building façade can occur potentially breaking into multiple levels prior to full evacuation and overwhelming automatic fire suppression systems. Multiple fires will also compromise the effectiveness of fire brigade intervention. The initial fire source may be external, typically occurring in waste materials at ground level or on balconies in addition to a fully developed fire breaking out of a building.

Typical scenarios are shown schematically in Figure 18

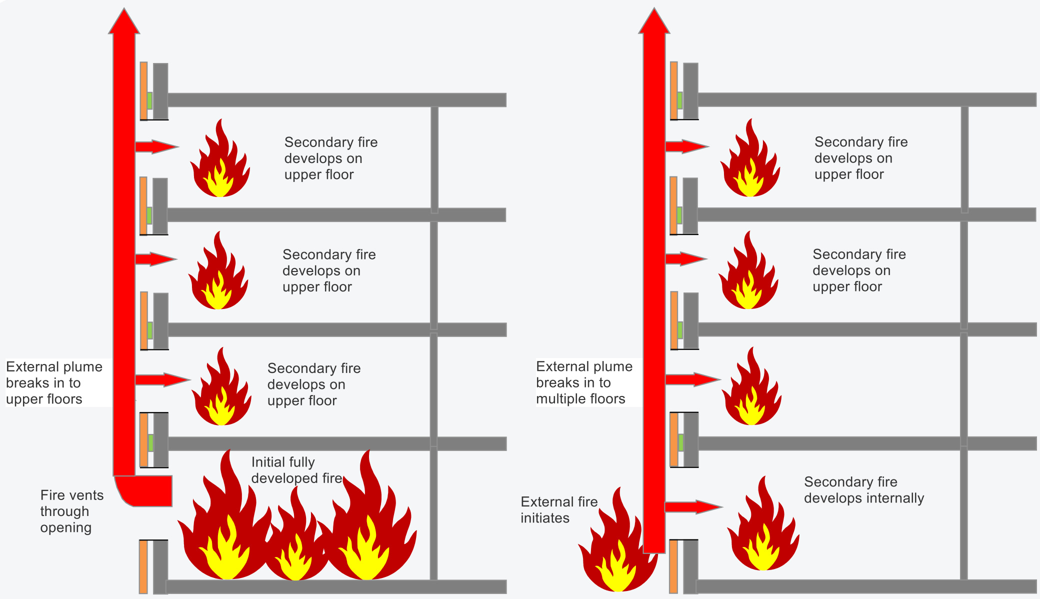


Figure 18: Fire Spread to multiple floors with highly combustible materials forming facade.

The current NCC does not provide *Deemed-to-Satisfy Solutions* for combustible cladding systems

Therefore if, for example, external timber screening is applied to external walls of buildings of Type A or B construction the *Performance Solution* pathway will need to be followed because the timber screening is combustible.

Verification Method CV3 provides a means of demonstrating compliance with CP2(a)(iv) in relation to combustible facades / combustible external walls but other *Assessment Methods* are also permitted.

The text box below is an extract from the NCC 2019 showing CV3 and a brief overview of the *Verification Method* follows:

CV3 Fire spread via external walls

Compliance with CP2 to avoid the spread of fire via the external wall of a building is verified when -

(a) compliance with CP2(a)(iii) to avoid the spread of fire between buildings, where applicable, is verified in accordance with CV1 or CV2, as appropriate; and

(b) the external wall system -

(i) has been tested for external wall (EW) performance in accordance with AS 5113; and

(ii) has achieved the classification EW; and

(iii) if containing a cavity, incorporates cavity barriers and these cavity barriers have been included in the test performed under (i) at the perimeter of each floor; and

(c) in a building of Type A construction, the building is protected throughout by a sprinkler system (other than a FPAA101D or FPAA101H system) complying with Specification E1.5 and has -

(i) sprinkler protection to balconies, patios and terraces, and where overhead sprinkler coverage is not achieved alongside the external wall, sidewall sprinkler heads are provided at the external wall for the extent of the balcony, patio, or terrace where overhead sprinkler coverage is not achieved; and

(ii) for a building with an effective height greater than 25 m -

(A) monitored stop valves provided at each floor level arranged to allow the isolation of the floor level containing the stop valve while maintaining protection to the remainder of the building; and

(B) the sprinkler system being capable of providing sufficient flow to serve the design area required by AS2118.1 for the relevant hazard class on each floor level plus the design area required by AS 2118.1 for the floor level above, except where the former level is -

(aa) the floor level below the uppermost roof; or

(bb) any floor level that is wholly below ground; and

(d) in a building of Type B construction, the building is -

(i) a Class 5, 6, 7 or 8 building or Class 4 part of a building; or

(ii) a Class 2, 3 or 9 building that -

(A) is protected throughout by a sprinkler system (other than a FPAA101D or FPAA101H system) complying with Specification E1.5; or

(B) has any openings in external walls separated by a slab or other horizontal construction complying withC2.6(a)(iv) as if the building were of Type A construction.

Clause (a) applies to the spread of fire between buildings rather than vertical fire spread via the external wall and requires *Verification Methods* CV1 and / or CV2 to be applied. Combustible materials may increase the radiant heat emitted from a building fire and potential for direct flame impingement if buildings are close together. Combustible materials are also susceptible to ignition if a major fire occurs in an adjacent building unless adequately protected or adequate separation distances from fire sources are provided. Refer to Section 5.1 for further information relating to CV1 and CV2.

Clause (b) requires that the external wall system to be tested for external wall (EW) performance in accordance with the requirements of AS 5113 [31] and achieve the EW classification.

CV3 differs from many other *Verification Methods* in the NCC in that it places a heavy reliance of a large-scale fire tests rather than calculations when carrying out the analysis and evaluation phases; although significant expert / engineering judgement will be required to ensure that the test is representative of the proposed installation.

AS 5113:2016: Classification of External walls of buildings based on reaction-to-fire performance, nominates appropriate test methods and specifies the required performance criteria that have to be satisfied to achieve the EW classification.

Fire tests can be performed to ISO 13785-2[32] or the BS8414 series [33, 34]. Generally, the BS8414 test methods are adopted since a number of accredited testing laboratories in Australia have facilities to test to BS 8414. However it should be noted that the AS 5113 test and performance criteria vary significantly from the criteria specified in the UK by Approved Document B [35] through reference to BR135 [36]. For example, AS 5113 specifies;

- performance criteria that apply throughout the 60 minute test duration
- criteria to debris falling from the test specimen
- more stringent criteria with respect to fire spread / incipient spread of fire.

The AS 5113 performance criteria for tests performed to BS8414 are summarised in Table 8 together with the intent of the criteria

Table 8: AS 5113 Criteria and Intent.

Intent:	Criteria
Reduced risk of fire spread to two or more levels above the floor of origin	Temperature 50mm from façade, 5m above opening shall not exceed 600°C
Reduced risk of incipient spread of fire to two or more levels above the floor of origin	Internal temperatures of materials and cavities 5m above opening shall not exceed 250°C
Reduced risk of fire spread to two or more levels above the floor of origin and lateral flame spread	Flame spread must not extend beyond the nominated specimen size
Reduce risk of fire spread to floors below	Continuous flaming on the ground for more than 20s from debris or molten material shall not occur
Control of debris falling from the test specimen	Total mass of debris shall not exceed 2kg
Reduce risk of fire spread to the floor above through wall if not fire resistant	Non-fire side temperatures measured 900mm above the opening shall not rise by more than 180K, flaming on the non-fire side should not occur and through openings should not occur

Clause (c) Applies to Type A construction (mid- and high-rise buildings) and additionally requires sprinkler protection including protection of balconies. For buildings with an effective height greater than 25m, additional enhancements to fire sprinklers are specified to enhance both the reliability of the sprinkler system and reduce the probability of the sprinkler system being overrun if fire spread to the next floor occurs.

Clause (d) applies to Type B construction (low-rise buildings) and for Class 2, 3 or 9 buildings requiring either sprinkler protection or having any openings in external walls separated by a slab or other horizontal construction complying withC2.6(a)(iv) as if the building were of Type A construction.

Notwithstanding the direct application of a fire tested system and additional mitigation measures specified in CV3, the fire safety engineer should consider the applicability of tested systems to the specific installation and the holistic design of the building to determine if any further mitigation measures are required and nominate requirements for commissioning and ongoing maintenance of fire safety systems.

In addition to information on data and methods in WoodSolutions Design Guide 18 useful information relating to the exposure of facades from mass timber compartment fires and a comparison with standard test method exposures, including BS8414, has been published by Brandforsk. (Sjöström [37])

5.3 Fire Safety Verification Method (CV4 / DV4 / EV1.1)

Verification Method CV4 / DV4 EV1.1 is also known as the Fire Safety *Verification Method* (FSVM) and is included in Schedule 7 of the NCC. It provides a process for the design and assessment of fire safety *Performance Solutions*. Whereas other fire safety *Verification Methods* (CV1-CV3) focus on specific applications such as spread of fire between buildings, the FSVM is suitable for general application and adopts a holistic approach to fire safety which is consistent with the structure of the NCC *Performance Requirements*. This is recognised by the *Verification Method* being cross-referenced in Sections C, D and E.

For further detail, reference should be made to the Fire Safety *Verification Method* Handbook [25] and supporting Annex[16] which includes data sheets providing useful supporting data and descriptions of methods.

The FSVM applies the following *Governing Requirements* to provide a *Verification Method* that is consistent with NCC compliance pathways for Performance Solutions;

- The concept of equivalence is applied whereby a similar (reference building) complying with the *DTS Provisions* is defined and the level of safety for the Proposed Performance Solution must be at least equivalent to that of the reference building. This approach provides a quantifiable benchmark against which compliance of a *Performance Solution* can be verified once the appropriate reference building has been selected.
- The FSVM must only be used by a *professional engineer* or other appropriately qualified person recognised by the *Appropriate Authority* as having qualifications and/or experience in the discipline of fire safety engineering. Thus, the *Evidence of Suitability* for the total fire safety strategy will be in the form of a report from a professional engineer consistent with other pathways for *Performance Solutions.*

The FSVM specifies a minimum of twelve design scenarios for consideration that are described in Table 9. Each design scenario is considered in one or more locations to compare the proposed solution against a reference building complying fully with the NCC DTS requirements and that is considered by the PBDB stakeholders to provide an acceptable level of safety.

This approach ensures that common critical design scenarios are considered but does not prevent additional design scenarios being considered if they are identified during the PBDB process.

Table 9: NCC Fire Safety Verification Method Design Scenarios. *This table is a derivative of Schedule 7 of the NCC 2019 Amendment 1 provided by the Australian Building Codes Board © 2020. (https://ncc.abcb.gov.au/)*

Ref	Design Scenario	Design Scenario Description
BE	Fire blocks *evacuation route*	A fire blocks an *evacuation route*
UT	Fire in a normally unoccupied room threatens occupants of other rooms	A fire starts in a normally unoccupied room and can potentially endanger a large number of occupants in another room
CS	Fire starts in concealed space	Flame spread must not extend beyond the nominated specimen size
	A fire starts in a concealed space that can facilitate fire spread and potentially endanger a number of people in a room	Continuous flaming on the ground for more than 20s from debris or molten material shall not occur
SF	Smouldering fire	A fire is smouldering in close proximity to a sleeping area
IS	Fire spread involving internal finishes	Interior surfaces are exposed to a growing fire that potentially endangers occupants
CF	Challenging fire	Worst credible fire in an occupied space
RC	Robustness check	The objectives of the NCC should be satisfied if failures of a critical parts of the fire safety systems fail
SS	Structural Stability and other properties	Building does not present risk to other properties in a fire event. Consider risk of structural failure
HS	Horizontal fire spread	A fully developed fire in a building exposes the external walls of a neighbouring building (or potential building) and vice versa
VS	Vertical fire spread involving cladding or arrangement of openings in walls	A fire source exposes a wall and leads to significant vertical fire spread
FI	Fire brigade intervention	Facilitate fire brigade intervention to the degree necessary
UF	Unexpected Catastrophic Failure	A building must not unexpectedly collapse during a fire event

The fire safety *Verification Method* process is shown in Figure 19 which has been extracted from the FSVM Handbook. Essentially the process is broken down into two stages the (1) Performance Based Design Brief and the (2) Performance Based Design Risk Assessment (Report). Each of these stages and the individual processes are described in detail in the Handbook.

Further data and worked examples demonstrating the use of the FSVM for timber structures are provided in the following WoodSolutions Technical Design Guides

- Wood Solutions Technical Design Guide 18 Fire Safe Design of Timber Structures - Methods of Analysis and Supporting Data (2021)
- Wood Solutions Technical Design Guide 19 Fire Safe Design of Timber Structures - Worked Examples of *Performance Solutions* (2021)

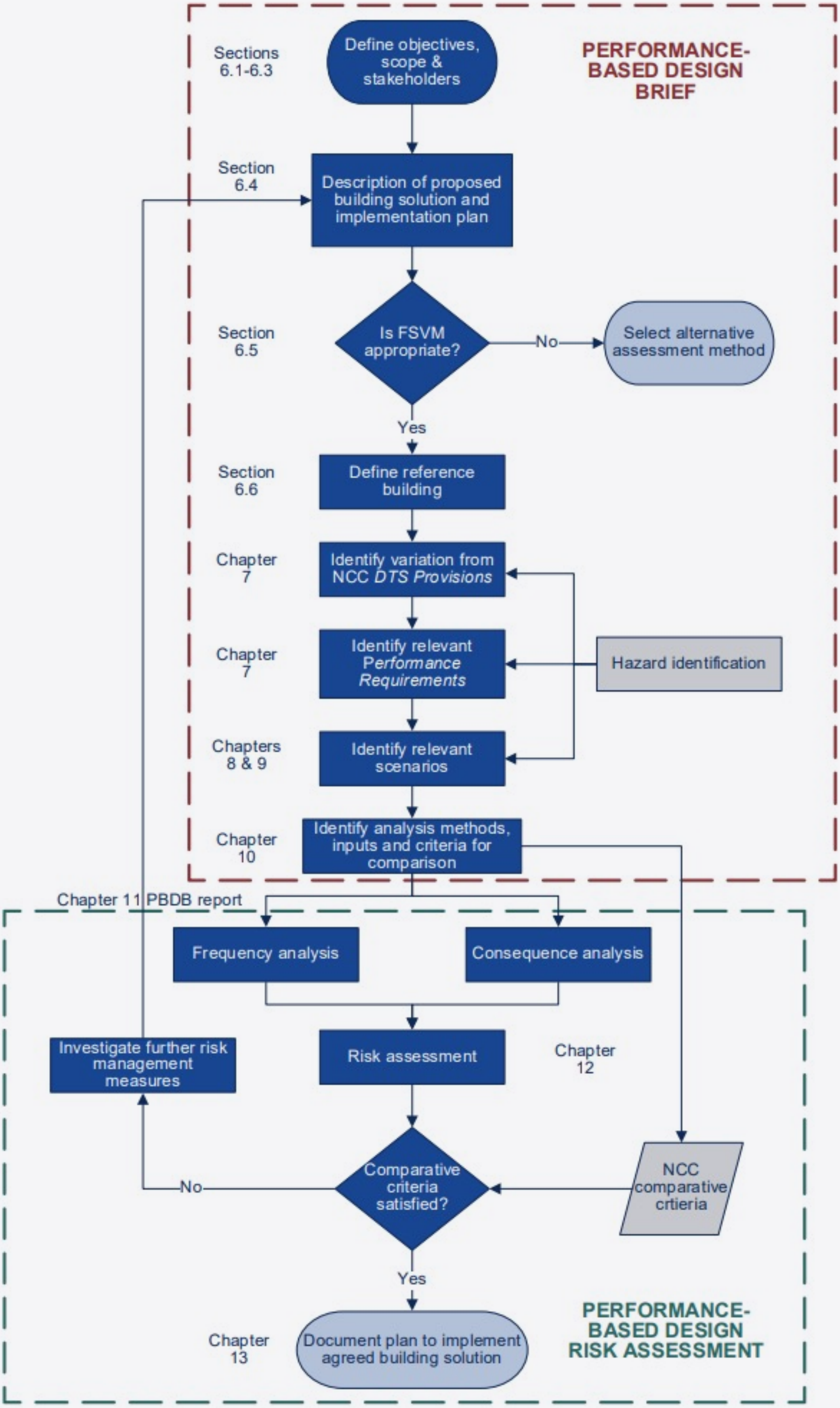


Figure 19 Fire Safety Verification Method Process (from the Fire Safety Verification Method Handbook). *The FSVM process flow chart was provided by the Australian Building Codes Board © 2019. Original content hosted on the ABCB website. (https://ncc.abcb.gov.au/sites/default/files/resources/2020//Handbook_Fire_Safety_Verification_Method.pdf)*

5.4 Absolute Assessment and Quantification of NCC Performance Requirements.

The NCC adopts a holistic approach to fire safety based on early work on a fire safety system approach described by Beck [11, 38, 39], the Draft National Safety Systems Code [40] and various Fire Code Reform Centre projects which informed the development of the performance based Building Code of Australia (NCC); and subsequent fire safety engineering guides prepared in Australia and internationally.

The holistic approach to fire safety recognises that the optimum fire safety solution for a building can only be identified by considering the interactions between fire safety sub-systems such as passive fire protection / structural design, active fire protection systems, fire brigade intervention and occupant behaviour and response etc.

It is therefore necessary for any quantification of the fire related Performance Requirements to be expressed in terms that facilitate holistic approaches to enable optimum solutions to be developed that are compatible with other design drivers and constraints.

It is planned to include quantified *Performance Requirements* for fire safety in the NCC 2022 and draft quantified *Performance Requirements* were released for public comment in May 2021 in the Public Comment Draft of the NCC 2022 [41]. A brief overview of the proposed approach is described below but it should be noted that these provisions may be subsequently modified after public comment. The copyright for the information, from which the information below has been derived, is owned by the Commonwealth of Australia and published by the Australian Building Codes Board © 2021.

Essentially there are two categories of criteria relating to:

- Life Safety; and
- Fire Spread

with the criteria for both categories requiring to be satisfied.

Quantified Life Safety Criteria

With respect to life safety, criteria are expressed in terms of tolerable individual and societal risks with upper and lower limits being specified.

If the lower tolerable limits (individual and societal) are not exceeded by the proposed Performance Solution, the individual and societal risk criteria can be considered to be satisfied.

If the upper tolerable limits (individual or societal) are exceeded by the proposed Performance Solution, the individual or societal risk criteria have not been satisfied and modifications to the proposed solution will be required.

If the individual and / or societal risks presented by the proposed *Performance Solution* lie between the lower and upper allowable risk limits, the proposed *Performance Solution* can be considered to meet the *Performance Requirements* for life safety, if it can be demonstrated that the individual and / or societal risk presented by the *Performance Solution* is less than or equal to that presented by a similar Deemed-to-Satisfy compliant reference building that is considered to represent a tolerable risk.

The following list identifies matters for consideration when undertaking the risk assessment and, whilst it is not definitive, it provides a useful check of some of the more common parameters that must be considered.

A comparison with the Performance Requirements in the NCC 2019 edition shows that the majority of the parameters are included within the current Performance Requirement structure but are consolidated into a single list.

(a) hazards, building characteristics and occupant characteristics including—

- (i) function or use of the building; and
- (ii) fire load; and
- (iii) potential fire intensity; and
- (iv) height of the building; and
- (v) number of storeys; and
- (vi) location in alpine areas; and
- (vii) proximity to other property; and
- (viii) size of any fire compartment / floor area; and
- (ix) other elements providing structural support; and
- (x) number, mobility and other occupant characteristics; and
- (xi) travel distance; and
- (xii) exit above and below ground; and

(b) prevention / intervention measures against hazards as applicable including—

- (i) control of linings, materials and assemblies to maintain tenable conditions for evacuation; and
- (ii) occupant intervention using firefighting equipment (fire hose reels and fire extinguishers); and
- (iii) automatic fire suppression; and
- (iv) fire brigade intervention, including- -
  - (A) fire brigade access; and
  - (B) fire hydrants; and
  - (C) fire control centres; and
  - (D) automatic notification of Fire Brigade; and
  - (E) emergency lifts; and

(c) means of managing the consequences, including—

- (i) maintaining building structural stability; and
- (ii) avoiding spread of fire to exits; and
- (iii) protection from spread of fire and smoke to allow for orderly evacuation as appropriate or as part of defend in place strategies or provisions of temporary refuges for occupants requiring assistance to evacuate; and
- (iv) behaviour of concrete external walls in fire; and
- (v) barrier protection from high hazard service equipment; and
- (vi) protection of emergency equipment; and
- (vii) fire protection of openings and penetrations; and
- (viii) provision of exits; and
- (ix) construction of exits; and
- (x) provision of fire isolated exits; and
- (xi) provisions for paths of travel to, through and from exits; and
- (xii) evacuation lifts; and
- (xiii) automatic warning for sleeping occupants; and
- (xiv) safe evacuation routes; options for consideration include one or more of the following if necessary:
  - (A) smoke detection; and
  - (B) smoke management systems; and
  - (C) automatic suppression; and
- (xv) visibility in an emergency including emergency lighting; and
- (xvi) identification of exits including exit signage; and
- (xvii) emergency warning and intercom systems.

Spread of Fire Criteria

The spread of fire criteria were broadly derived from *Verification Methods* CV1 to CV3 and Deemed-to-Satisfy criteria relating to maximum compartment sizes with probability criteria included with the aim of maintaining similar levels of redundancy to current NCC provisions.

The relevant parameters from those identified for life safety should be considered.

It should be noted that both life safety and spread of fire criteria apply and satisfying the spread of fire criteria does not necessarily mean that the tolerable life safety criteria have been satisfied with respect to structural fire resistance for example.

6

NCC Assessment Methods for DTS Solutions and Detailed Documentation of Fire Safety Provisions

6.1 Overview of Assessment Methods for DTS Provisions and Detailed Documentation

Depending upon the compliance pathway, the proposed fire safety strategy will be described in either a Performance-based Design Report or a DTS Design Report which may be incorporated in an early version of a Building Manual. Whichever pathway is selected, the strategy then needs to be translated into detailed documentation for the required fire safety measures supported by *Evidence of Suitability* and *Expert Judgement* as shown in Figure 20.

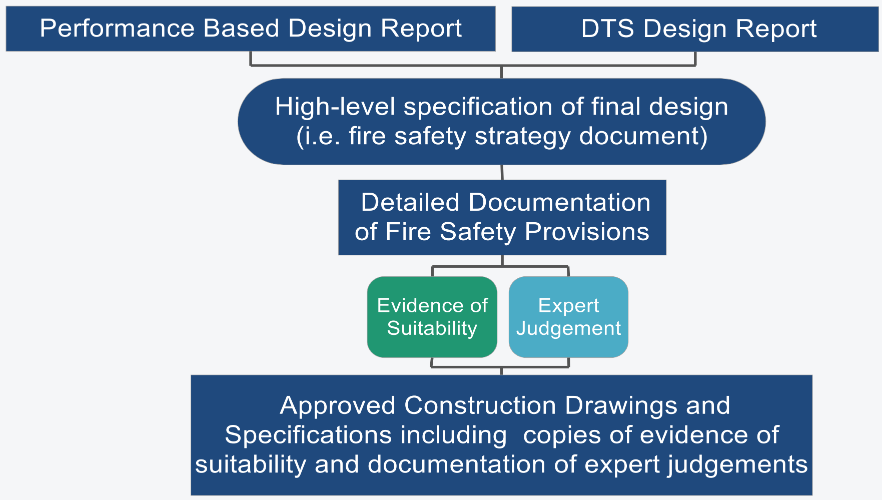


Figure 20: Overview of Procedure for Demonstrating Compliance with the NCC.

The design process for fire resistant timber structural elements is described in Chapter 4. Typically, when adopting the *Performance Solution* pathway, it is necessary to consider the fire dynamics of the compartment fire to determine the fire exposure, undertake heat transfer analysis and then determine the element or structure's functional performance.

Once this stage is undertaken, it is then necessary to specify the products and systems for construction purposes in a manner that is easily understood by product suppliers and installers and that enables the compliance with the specifications to be reliably determined by the design team and appropriate authorities. It is also important to specify the products and systems such that if an installation is damaged, it is possible to source materials that can reinstate the performance and for which appropriate *Evidence of Suitability* can be provided.

A practical way of achieving this is to express the performance of systems using terms, procedures and test methods that are consistent with NCC *DTS Provisions*.

For example, when expressing requirements for fire-protected timber or encapsulation of timber to prevent ignition, the required performance can be expressed in terms of the resistance to incipient spread of fire, non-combustibility, and the fire resistance performance of the protected timber member. Where consideration of delamination or self-extinguishment of exposed timber is a critical criterion, the fire exposure may be expressed in terms of an equivalent fire resistance test exposure / low oxygen concentration for a ventilation controlled fire followed by a controlled cooling rate with higher oxygen concentrations simulating transition to a fuel controlled regime with a greater tendency to support smouldering combustion. Further information on treatments of delamination and self-extinguishment are provided in Design Guide 18.

The remainder of this chapter focusses on specification of timber-based materials and elements of construction using Evidence of Suitability in a manner consistent with the following NCC DTS Provisions.

- A5.4 / Schedule 5 Fire-resistance of building elements
- A5.6 Resistance to the Incipient Spread of Fire
- Specification C1.13a Fire Protected Timber Requirements
- A5.5 Fire hazard properties
- Schedule 2 Definition of Non-Combustible

6.2 A5.4 / Schedule 5 Fire Resistance of Building Elements

Application and Definitions

Clause A5.4 of the *Governing Requirements* requires that the Fire Resistance Level (FRL) must be determined in accordance with Schedule 5 if the *Deemed-to-Satisfy* pathway is adopted. Where a *Performance Solution* can specify the fire resistance performance of an element in terms of an FRL, clause A5.4 should be applied.

Note: Where the resistance to fire of elements of construction is not expressed in terms of FRL, appropriate means of independent verification of performance should be specified (including performance criteria)

The definitions in the text box below (from NCC 2019 [3]) are relevant to the following discussion:

Fire-resisting-

- *For the purposes of Volume One, applied to a building element, means having an FRL appropriate for that element.*
- *For the purposes of Volume Two, applied to a structural member or other part of a building, means having the FRL required for that structural member or other part.*

Fire-resistance level (FRL) *means the grading periods in minutes determined in accordance with Schedule 5, for the following criteria—*

(a) structural adequacy; and

(b)integrity; and

(c)insulation,

and expressed in that order.

A dash means that there is no requirement for that criterion. For example, 90/–/– means there is no requirement for an FRL for integrity and insulation, and –/–/– means there is no requirement for an FRL.

Standard Fire Test *means the Fire-resistance Tests of Elements of Building Construction as described in AS 1530.4*

The Standard Fire Test

The standard fire resistance test method is AS 1530.4[42]. It requires a representative specimen of an element of construction to be exposed to the “standard” time/temperature regime shown in Figure 21. Typically, vertical specimens 3m x 3m and horizontal specimens 4m x 3m are tested unless the use of smaller specimens is permitted. Refer Figure 22 and Figure 23 for examples of typical loadbearing timber floor and wall tests. Loadbearing elements are normally subjected to typical load combinations that apply to the fire limit state although other loads can be applied for example if lower loadings are applicable to limit defections.

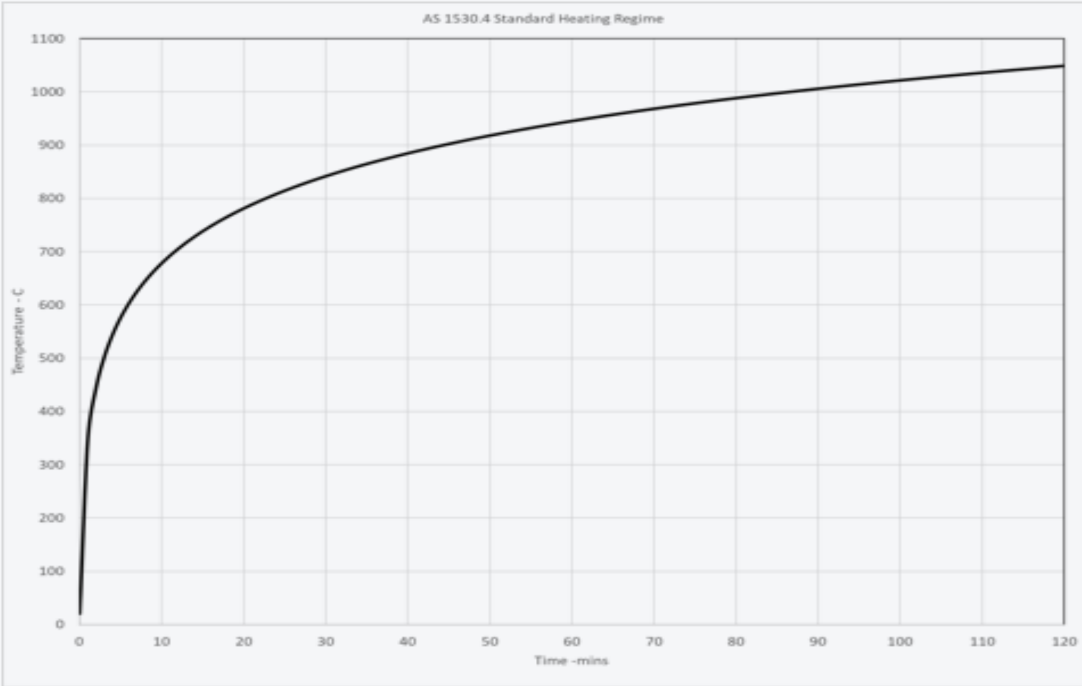
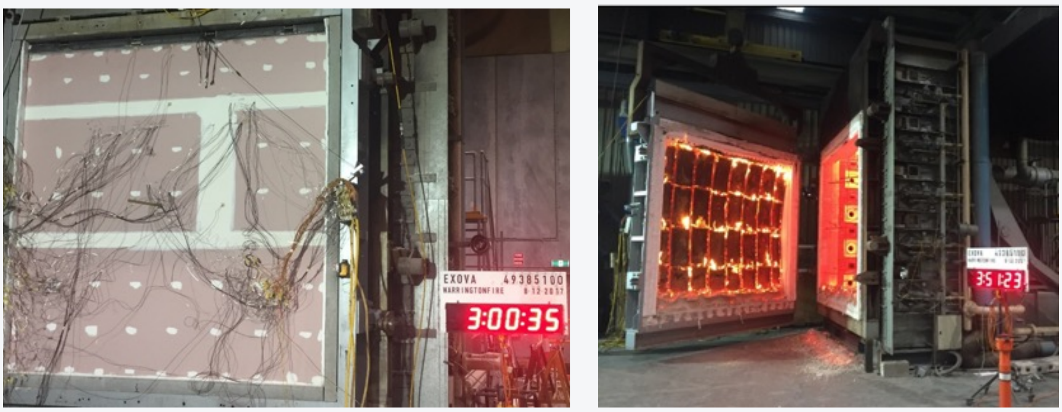


Figure 21: Standard Heating Regime of AS 1530.4.

Non-fire side after 90 minutes of test

Fire-exposed face after removal from the furnace

Figure 22: Loadbearing Light-weight timber framed floor FRL of 90/90/90 RISF>60mins at end of test.



Non-fire side after 180 minutes with full test load applied

Fire Exposed face 4 minutes after removal from furnace (Test was continued to 227 minutes under reduced load)

Figure 23 Loadbearing Timber Stud wall with cavities filled with high-performance mineral fibre FRL 180/180/180 RISF>120mins

Observations are made on the performance of the specimen while it is subjected to thermal and, where applicable, physical loading and the elapsed times at which failures under various criteria occur are recorded.

The most common performance criteria are summarised below:

Structural adequacy - The ability of a load-bearing element of construction to support a load

Integrity - The ability of an element of construction to resist the passage of flames and hot gases from one space to another

Insulation - The ability of an element of construction to maintain a temperature on the surface that is not exposed to the furnace, below the limits specified in order to prevent the spread of fire.

Other criteria such as radiant heat flux and *Resistance to the Incipient Spread of Fire* may be applied to specific circumstances.

Schedule 5 Clause 2 sets out the procedures for determining the FRL of building elements.

These procedures can be grouped as follows.

- Prescribed forms of construction (none of the prescribed forms of construction relate to timber construction and therefore no further discussion of this approach is provided in this publication).
- Performance determined by exposure to a standard fire test
- Nominated Design Standards / Specifications

Schedule 5 Clause 2 of the NCC is reproduced in the following text box.

Schedule 5 Clause 2 Rating

A building element meets the requirements of this Schedule if—

(a) it is listed in, and complies with Table 1 of this Schedule; or

*(b) it is identical with a prototype that has been submitted to the **Standard Fire Test**, 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 an Accredited Testing Laboratory which -*

(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

(c) it differs in only a minor degree from a prototype tested under (b) and the FRL attributed to the building element is confirmed in a report from an Accredited Testing Laboratory which -

(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; or

(d) it is designed to achieve the FRL in accordance with -

(i) AS/NZS 2327, AS 4100 and AS/NZS 4600 if it is a steel or composite structure; or

(ii) AS 3600 if it is a concrete structure; or

*(iii) AS 1720.4 if it is a timber element other than **Fire-protected Timber**; or*

(iv) AS 3700 if it is a masonry structure; or

(e) the FRL is determined by calculation based on the performance of a prototype in the Standard Fire Test and confirmed in a report in accordance with Clause 3; or

*(f) for **Fire-protected Timber,** it complies with Specification C1.13a where applicable.*

The emphasis of Schedule 5 relates to structural elements but there are numerous other elements to which the standard fire test applies either by direct reference in the NCC or via reference documents such as 1905.1 (fire doors) or AS 4072.1 (service penetrations and fire dampers). Elements addressed by AS 1530.4 include:

- Walls,
- Floors, roofs, and ceilings
- Columns
- Beams Girders and Trusses
- Doorsets and Shutter Assemblies
- Service penetrations and control joints
- Fire damper and air transfer grille assemblies
- Uninsulated glazing
- Critical Services.

For elements other than structural elements, the most common options for determining FRLs are standard fire testing and subsequent assessments of minor variations from the tested prototype by *Accredited Testing Laboratories*.

Performance Determined by Exposure to a Standard Fire Test

There are three options for determining the FRL of timber elements of construction by exposure to the standard fire test:

1) The element is identical with a prototype that has been submitted to the Standard Fire Test, 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 an Accredited Testing Laboratory. In most cases there will be variations from the tested prototype which is addressed by the following approaches.

2) The element differs in only a minor degree from a tested prototype as described above and the FRL attributed to the building element is confirmed in a report from an Accredited Testing Laboratory which -

   (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; or

3) The FRL of an element is determined by calculation based on the performance of a prototype in the Standard Fire Test and confirmed in a report in accordance with Clause 3 which allows building elements to vary with respect to:

   - length and height if it is a wall; and
   - height if it is a column; and
   - span if it is a floor, roof or beam; and
   - conditions of support; and
   - to a minor degree, cross-section and components; and

   demonstrates by calculation that the building element would achieve the FRL if it is subjected to the regime of the Standard Fire Test in relation to -

   - structural adequacy (including deflection); and
   - integrity; and
   - insulation; and

   the calculations must account for

   - the temperature reached by the components of the prototype and their effects on strength and modulus of elasticity; and
   - appropriate features of the building element such as support, restraint, cross-sectional shape, length, height, span, slenderness ratio, reinforcement, ratio of surface area to mass per unit length, and fire protection; and
   - features of the prototype that influenced its performance in the Standard Fire Test although these features may not have been taken into account in the design for dead and live load; and
   - features of the conditions of test, the manner of support and the position of the prototype during the test, that might not be reproduced in the building element if it is exposed to fire; and
   - the design load of the building element in comparison with the tested prototype.

Option 3 is used relatively infrequently since, based on its content, it is generally restricted to structural elements and it is more common for a “field of application” to be defined in an assessment from an *Accredited Testing Laboratory* using options 1 and 2 with the tests being designed to yield the necessary information for the assessment.

*Note: **Where Evidence of Suitability** is in the form of a report or reports from an **Accredited Testing Laboratory** the designer should:*

- *Obtain complete copies of the relevant report(s) issued by the laboratory which must:*

  (i) describe the method and conditions of the test and the form of construction of the tested prototype in full; and certify that the application of restraint to the prototype complied with the Standard Fire Test,

  and where variations from the tested prototype are considered;

  (ii) identify the variations from the tested prototype, describe the materials, construction and conditions of restraint which are necessary to achieve the FRL and certify that the building element is capable of achieving the FRL despite the minor departures from the tested prototype.

- *Check the reports are complete and are current.*

  Note: Most assessments of variations issued by NATA accredited laboratories nominate a termination date after which the assessment must be reviewed. From May 2022 the NCC will require tests to be undertaken to the current edition of the NCC or the performance of the element to be assessed by an Accredited Testing Laboratory against the current edition of a standard.

- *Check that the relevant laboratory is accredited for the relevant test and retain documentation from this check for submission to the **Appropriate Authority**. (This information can be obtained from the NATA web site; https://nata.com.au/accredited-facility)*

- *Retain appropriate documentation from an appropriately qualified person (including their qualifications and experience) determining that the design details and subsequently installation are either identical to the tested prototype or comply with the variations and conditions nominated in an assessment of a variation from the tested prototype*

- *Provide the above information in the Building Manual or equivalent Document (Refer Section 1.4)*

Element designed to achieve an FRL in accordance with a nominated design standard

Schedule 5 allows elements of construction to be designed to achieve prescribed FRLs in accordance with nominated design standards which include AS 1720.4 Timber structures—fire resistance for structural adequacy of timber members [18]

Typically, these designs are undertaken by professional structural and or fire engineers or other appropriately qualified persons and evidence of compliance should be provided as described in the text box below.

Evidence of compliance is typically a report from a professional engineer or appropriately qualified person which:

- *certifies that the form of construction is likely to fulfill the specific requirements of the NCC (e.g., FRL 120/–/–), and*
- *sets out the basis on which it is given and the extent to which relevant standards, specifications, rules, codes of practice, other publications, tests, and inspections have been relied upon to determine it fulfills the specific requirements of the NCC.*

A complete copy of the report and any supporting documents including details of the experience and qualifications of the report author should be included with the design documentation forwarded to the Appropriate Authority. The designer should be satisfied that the author has the appropriate expertise and experience before forwarding the documentation. These documents should also be included in the Building Manual.

Where confirmation is required after installation any tests and inspections should be documented in addition to the above information and provided in the appropriate version of the Building Manual.

Other Evidence of Suitability

If any other form of *Evidence of Suitability* is presented to demonstrate compliance with FRLs for a *Deemed-to-Satisfy Solution*, it does not waive the need comply with Schedule 5.

Therefore, product certification and accreditation and any other evidence must be supported by documentation complying with the requirements of Schedule 5 (e.g., a complete copy of the original test reports and / or reports from an Accredited Test Laboratory).

Where manufacturers or installer statements of compliance are made, they may provide some level of additional confidence that the supplier has confirmed the performance of the product, but the supporting documentation must still include complete copies of test reports, assessment reports, inspections and reports from professional engineers or an appropriately qualified person as appropriate.

6.3 Evidence of Suitability - Resistance to the Incipient Spread of Fire

The NCC defines Resistance to the Incipient *Spread of Fire* as follows

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 roof, or ceiling and floor above, so as to limit the temperature rise of materials in this space to a level which will not permit the rapid and general spread of fire throughout the space.

Resistance to the Incipient Spread of Fire is determined by subjecting a ceiling system to a standard fire resistance test (AS 1530.4). Temperatures are monitored on the upper surface of the ceiling at prescribed positions and if the measured temperatures are maintained below the maximum permitted temperature (250°C), a *Resistance to the Incipient Spread of Fire* can be assigned, which is the time in minutes for which temperatures were maintained below the prescribed temperature or the end of the test whichever is less.

The above criteria are also consistent with criteria for limiting interface temperatures for light-weight fire-protected timber elements (refer Section 6.4 and Appendix D *Evidence of Suitability for Fire-protected Timber* for further details) or the derivation of levels of protection for *Performance Solutions* requiring encapsulation to prevent ignition of timber structural elements.

Similar to elements required to achieve an FRL; a ceiling is deemed to have a *Resistance to the Incipient Spread of Fire* to the space above if:

- it is identical with a prototype that has been submitted to the Standard Fire Test and the *Resistance to the Incipient Spread of Fire* achieved by the prototype is confirmed in a report from an Accredited Testing Laboratory that
  - describes the method and conditions of the test and form of construction of the tested prototype in full and
  - certifies that the application of restraint to the prototype complies with the Standard Fire Test; or
- it differs in only a minor degree from a prototype and the *Resistance to the Incipient Spread of Fire* attributed to the ceiling is confirmed in a report from an Accredited Testing Laboratory that:
  - certifies that the ceiling is capable of achieving the Resistance to the *Incipient Spread of Fire* despite the minor departures from the tested prototype; and
  - describes the materials, construction and conditions of restraint that are necessary to achieve the *Resistance to the Incipient Spread of Fire*.

Evidence of Suitability must therefore be in the form of a report or reports from an *Accredited Testing Laboratory* as detailed for elements required to achieve FRLs Refer Section 6.2 for further details.

6.4 Evidence of Suitability Fire-protected Timber

The NCC provisions include enhanced requirements for fire-protected timber elements of construction in addition to the prescribed FRL to compensate for the relaxation of the requirements for elements of construction to be non-combustible or of masonry or concrete construction. The requirements for fire protected timber are provided in Specification C1.13a of the NCC and include requirements for:

- Non-combustible coverings to be used
- Extended application of the *Resistance to the Incipient Spread of Fire* criteria to walls as well as ceilings.
- Modified *Resistance to the Incipient Spread of Fire* criteria for application to *Massive timber* construction
- Use of cavity barriers within some elements of construction
- Where cavities are present any insulation within the cavities must be non-combustible

Generally, the requirements for E*vidence of Suitability* for fire-protected timber are consistent with those for fire-resistant building elements except that:

- calculation of the FRL in accordance with methods such as AS 1720.4 is not permitted. (i.e., FRL performance has to be determined on the basis of AS 1530.4 fire tests), and
- *Evidence of Suitability* verifying coverings and insulation are non-combustible is required, and
- *Evidence of Suitability* that the resistance to incipient spread of fire or modified criteria have been satisfied (for walls and ceilings) is required, and
- *Evidence of Suitability* for internal cavity barriers if they are required for the form of timber elements selected.

Most of the above *Evidence of Suitability* will be in the form of test reports from *Accredited Test Laboratories*. Further details and discussion relating to appropriate *Evidence of Suitability* for fire-protected timber are provided in Appendix D. An example of a data sheet nominating appropriate *Evidence of Suitability* for an external wall is also provided in Appendix E.

6.5 Fire Hazard Properties

Introduction to fire hazard property tests and evidence of suitability

The guide to the NCC states "A material's fire hazard properties are an indication of its susceptibility to the effects of flame or heat, particularly during the early stages of a fire". Perhaps a clearer understanding of the intent of controlling fire hazard properties can be obtained from consideration of the definition of fire hazard in the NCC, provided in the text box below:

> ***Fire hazard** means the danger in terms of potential harm and degree of exposure arising from the start and spread of fire and the smoke and gases that are thereby generated.*

Therefore, it is reasonable to conclude that the intent of controlling the fire hazard properties of materials is to minimise the potential harm and degree of exposure resulting from ignition and spread of fire and the generation of smoke and hot gases. The relevant *Performance Requirement* is CP4 which, is consistent with this interpretation, is summarised below:

CP4 Safe conditions for evacuation

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.

Wood products are a popular choice for floor wall and ceiling linings and may be applied as attachments to structural elements or in the case of exposed *Massive timber* elements the fire hazard properties also apply to the exposed timber elements.

The majority of the NCC Deemed-to-Satisfy Fire Hazard Properties requirements are specified in Specification C1.10 of NCC Volume One and the nominated tests and performance / classification criteria are summarised below:

As the classification of these materials is by means of test, *Evidence of Suitability* will normally be in the form of a test or classification / assessment based on one or more tests prepared by a test laboratory. Whilst the NCC does not prescribe the use of an *Accredited Testing Laboratory* for fire hazard property tests, the laboratory accreditation process provides added confidence in the results obtained. It is therefore recommended that the *Evidence of Suitability* obtained is in the form of a report from an *Accredited Testing Laboratory*.

The following sections describe common test methods used by the *DTS Provisions* which in many cases are also appropriate for specification of required performance that have been derived for *Performance Solutions*.

Fire hazard properties – floor linings AS ISO 9239.1

AS ISO 9239.1 [43] Reaction to fire tests for floorings Part 1: Determination of the burning behaviour using a radiant heat source is the prescribed test method. It is an intermediate scale test simulating the thermal radiation levels likely to impinge on the floor of a corridor from the hot layer from a fire in an adjacent room or compartment. The test specimen is placed in a horizontal position below a gas-fired radiant panel inclined at 30°. A pilot flame is applied to the hotter end of the specimen. Results are expressed in terms of, the critical heat flux at extinguishment and smoke density versus time.

Critical Heat Fluxes of not less than 1.2, 2.2, or 4.5 kW/m^2 are prescribed by the NCC depending on the application.

Smoke developed index of not greater than 750 percent-minutes applies in buildings not protected by nominated types of sprinkler system.

Most commonly used wood products do not exceed the Smoke Developed Index limit of 750 percent-minutes and achieve Critical Heat Fluxes greater than 2.2 kW/m^2 with a minimum timber thickness of 12mm when mounted on an appropriate substrate or 17mm with an airgap behind the boards. It should be noted that some timber species achieve Critical Heat Fluxes greater than 4.5 kW/m^2 or greater than 2.2kW/m^2 with thicknesses less than the above thickness limits.

Reference should be made to WoodSolutions web-site for further information and *Evidence of Suitability.* (https://www.woodsolutions.com.au/articles/fire-test-reports)

Fire hazard properties – wall and ceiling linings AS 5637.1

AS 5637.1 [10] Determination of fire hazard properties, is a classification standard that defines how the fire hazard properties of wall and ceiling linings are classified using the following test methods as appropriate:

- AS ISO 9705 – 2003 [44] Fire tests—Full-scale room test for surface products
- AS /NZS 3837 [45] Method of test for heat and smoke release rates for materials and products using an oxygen consumption calorimeter.
- ISO 5660-1 [46] Reaction-to-fire tests — Heat release, smoke production and mass loss rate - Part 1: Heat release rate (cone calorimeter method) and smoke production rate (dynamic measurement)

The primary basis for classification of wall and ceiling linings is the time to flashover and the Smoke Growth Rate Index determined in an AS / ISO 9705 test

The lining material / system is fitted to the walls and ceiling of the test room and a heat source comprising a gas burner is located in the corner of the room and the time to flashover and smoke growth rate are determined.

Since AS/ISO 9705 tests are costly and correlations have been developed from bench-scale cone calorimeter tests for some materials, AS 5637.1 provides a pathway for classification to be based on cone calorimeter tests performed in accordance with AS 3837 tests and ISO 5660-1 but only if there are correlations for the materials. Detailed guidance is provided in AS 5637.1.

Wall and ceiling linings are assigned a Group number based on the time to flashover in a room test as follows with additional smoke criteria being applied if buildings are not protected by a nominated fire sprinkler system.

- Group 1 Materials do not reach flashover when exposed to 100kW for 600s followed by exposure to 300kW for 600s.
- Group 2 Materials reach flashover following exposure to 300kW within 600s after not reaching flashover when exposed to 100kW for 600s.
- Group 3 Materials reach flashover in more than 120s but within 600s when exposed to 100kW.
- Group 4 Materials reach flashover within 120s when exposed to 100kW.

The NCC DTS provisions specify the required Group Number, depending on the location within a building, class of building and presence of a nominated sprinkler system.

The Smoke Growth Rate Index should be not more than 100 if a building is not protected by a nominated sprinkler systems. If bench scale cone calorimeter tests are permitted to be used for classification an average specific extinction area limit of 250 m^2/kg is applied instead of the Smoke Growth Rate Index.

*Note: The **Evidence of Suitability** should be in the form of a report providing a classification to AS 5637.1 and if reliance is placed on cone calorimeter tests the report must identify that there are appropriate correlations to estimate the time to flashover.*

Most commonly used wood products achieve Group 3 performance with either a Smoke Growth Rate Index less than 100 or an average specific extinction area less than 250 m^2/kg although the Group Number can be reduced to 1 or 2 with appropriate fire-retardant treatments. Reference should be made to WoodSolutions web-site (https://www.woodsolutions.com.au/articles/fire-test-reports) for further information and *Evidence of Suitability*.

*Note: The NCC **DTS Provisions** prohibit the use of fire retardant coatings to modify the fire hazard properties and therefore a **Performance Solution** is required for these applications*

Fire Hazard properties other materials AS 1530.3

AS 1530.3 [47] *Methods for fire tests on building materials, components and structures Part 3: Simultaneous determination of ignitability, flame propagation, heat release and smoke release* is the prescribed test method used for control of various miscellaneous materials under the DTS Provisions. The method was originally developed for evaluation of wall and ceiling linings but was superseded by the Group number classification system. It has been retained in the NCC for various miscellaneous applications but there is little information to justify the performance levels specified.

The test method examines the reaction of a sample of the material, 600mm x 450mm, of normal in use thickness, orientated vertically when subjected to radiant heat and exposed to a piloted ignition source. The specimen progressively moves towards the radiant panel with a small flaming ignition source applied to volatiles.

The following indices are derived:

- Ignitability (range 0 to 20)
- Spread of Flame (range 0 to 10)
- Heat Evolved (range 0 to 10)
- Smoke Developed (range 0 to 10)

The lower the index the better the performance.

The NCC only applies the following two criteria;

- Spread of flame (indices of 0, 5 and 9 are commonly applied)
- Smoke developed (indices of 2 to 8 are commonly applied)

For common timbers, the Spread of Flame Indices are generally less than 9 and Smoke Developed Indices are generally 5 or less.

Reference should be made to WoodSolutions web-site (https://www.woodsolutions.com.au/articles/fire-hazard-properties-c110-materials-and-assemblies) for further information.

Schedule 6 of the NCC is required to be applied by Specification C1.10, where the outer layers of an assembly screen their core materials (e.g., composite panel).

Schedule 6 requires a determination of the ability to prevent ignition and screen the core material from free air by exposing a sample of minimum size 900mm x 900mm to the standard heating regime of AS 1530.4 for a period of 10 minutes. The specimen must include all types of joints, perforations and recesses or the like for pipes, light switches, or other fittings.

6.6 Non-combustible materials and construction – AS 1530.1

The specification of non-combustible materials and construction has broader application than the fire hazard properties and can relate to the reaction of materials to fire during the fully developed phase as well as the early stages of the fire. The NCC defines non-combustible as follows:

Non-combustible means

- **applied to a material - not deemed combustible as determined by AS 1530.1 - Combustibility Tests for Materials; and**
- **applied to construction or part of a building - constructed wholly of materials that are not deemed combustible.**

AS 1530.1[48] Methods for fire tests on building materials, components and structures Part 1: Combustibility test for materials is the prescribed test method. A specimen (45mm diam x 50mm high), is inserted into a specimen holder which is then placed within a pre-heated furnace at an initial temperature of approximately 750°C.

Temperatures are measured by the furnace and both specimen thermocouples and recorded until the test is terminated in accordance with the standard. Mass loss is also measured and sustained flaming from the specimen is observed.

A material is classified as combustible if any of the following occur:

- The mean duration of sustained flaming (for periods longer than 5s) is other than zero. (i.e., if sustained flaming for longer than 5s occurs)
- The mean furnace thermocouple temperature rise, exceeds 50°C.
- The mean specimen surface thermocouple temperature rise exceeds 50°C.

Wood products are combustible when tested to this method, but the combustibility criteria are applied to fire-protective coverings and insulation materials associated with fire-protected timber and may apply to other encapsulation systems adopted for Performance Solutions.

A

Appendix A - Abbreviations and Definitions

Abbreviations

ABCB – Australian Building Codes Board

DTS – *Deemed-to-Satisfy*

FPT – *Fire-protected timber*

MRISF – Modified *Resistance to the Incipient Spread of Fire*

NCC – National Construction Code

PBDB – Performance-based design brief

RISF – *Resistance to the Incipient Spread of Fire*

TFC – Timber-framed Concession

Definitions

Definitions in italics are defined terms within the NCC and these definitions were provided by the Australian Building Codes Board © 2020.

Appropriate Authority means the relevant authority with the statutory responsibility to determine the particular matter.

Assessment Method means a method that can be used for determining that a *Performance Solution* or *Deemed-to- Satisfy Solution* complies with the *Performance Requirements*

Deemed-to-Satisfy Provisions means provisions which are deemed to satisfy the *Performance Requirements*.

Deemed-to-Satisfy Solution means a method of satisfying the *Deemed-to-Satisfy Provisions*

Evidence of Suitability means, in the context of the NCC, one of the nominated types of Evidence of Suitability nominated as being acceptable in the NCC for the relevant application(s)

Encapsulated timber means timber which is encapsulated by *fire-protective coverings* to prevent the underlying timber igniting for either a prescribed time period when exposed to a prescribed fire exposure, or in relation to fully encapsulated timber, for the entire fire duration, including the fire growth, fully developed, decay cooling phases.

Expert Judgement means the judgement of an expert who has the qualifications and experience to determine whether a *Performance Solution* or *Deemed-to-Satisfy Solution* complies with the *Performance Requirements*.

Explanatory Information: Contemporary and relevant qualifications and/or experience are necessary to determine whether a *Performance Solution* complies with the *Performance Requirements*. The level of qualification and/or experience may differ depending on the complexity of the proposal and the requirements of the regulatory authority. Practitioners should seek advice from the authority having jurisdiction or *Appropriate Authority* for clarification as to what will be accepted.

Note: In engineering disciplines the term engineering judgement is commonly used when making decisions or judgements rather than expert to indicate that the judgements made are typical of those made routinely by a competent professional engineer. The process may be formal, intuitive, or deliberate or, in most cases, a combination of the three.

Fire-hazard Properties means the following properties of a material or assembly that indicate how they behave under specific fire test conditions:

(a) *Average specific extinction area, critical radiant flux,* and *Flammability Index*, determined as defined in Schedule3.

(b) *Smoke-Developed Index, smoke development rate* and *Spread-of-Flame Index*, determined in accordance with Schedule 6.

(c) *Group number* and *smoke growth rate index* ($SMOGRA_{RC}$), determined in accordance with Specification C1.10 of Volume One.

Fire-protected Timber means *fire-resisting* timber building elements that comply with Volume One Specification C1.13a of the NCC

Fire Protective Covering – in the context of fire-protected timber in the NCC means a non-combustible covering complying with the requirements of specification C1.13a. Note this differs from the standard definition provided within the NCC for fire protective coverings.

Fire-resistance level (FRL) means the grading periods in minutes determined in accordance with Schedule 5 of the NCC, for the following criteria—

(a) structural adequacy; and
(b) integrity; and
(c) insulation,

and expressed in that order.

Note: A dash means that there is no requirement for that criterion. For example, 90/–/– means there is no requirement for an FRL for integrity and insulation, and –/–/– means there is no requirement for an FRL.

Fire Resisting for the purposes of Volume One of the NCC, applied to a building element, means having an FRL appropriate for that element.

Fire safety strategy means a strategy that defines the combination of measures that are required to satisfy the fire safety objectives and includes physical and human measures

Fire Safety Engineer or Fire Engineer means a professional fire engineer with appropriately qualifications and experience. Note: National and State based accreditation of fire safety engineers is available. When relying on a certificate or report from a fire engineer it is prudent to check the credentials of the relevant engineer and recognition of the accreditation within the State or Territory in which the building works is to be undertaken. Legislation within a State or Territory often includes requirements for insurance of practitioners such as Fire Safety Engineers

Governing Requirements means rules and instructions for using and complying with the NCC

Massive timber means an element not less than 75 mm thick as measured in each direction formed from solid and laminated timber

Modified *Resistance to the Incipient Spread of Fire* means the modified criteria used to determine the performance of fire protective coverings applied to *Massive timber*

Performance Solution means a method of complying with the Performance Requirements other than by a Deemed-to-Satisfy Solution.

Performance Requirement means a requirement which states the level of performance which a *Performance Solution* or *Deemed-to-Satisfy Solution* must meet.

Performance-based design brief (PBDB) means the process and the associated report that defines the scope of work for the performance-based analysis, the technical basis for analysis, and the criteria for acceptance of any relevant *Performance Solution* as agreed by stakeholders.

Resistance to the Incipient Spread of Fire, means the ability of the membrane to insulate the space between the ceiling and roof, or ceiling and floor above, so as to limit the temperature rise of materials in this space to a level which will not permit the rapid and general spread of fire throughout the space. Note: This definition is expanded to include walls in Specification C1.13a

Verification Method means a test, inspection, calculation, or other method that determines whether a *Performance Solution* complies with the relevant *Performance Requirements*.

B

Appendix B - Timber Framed Concessions from NCC Specification C1.1

The following clauses from the NCC were provided by the Australian Building Codes Board © 2020.

3.10 Class 2 and 3 buildings: Concession

(a) In a Class 2 or 3 building with a *rise in storeys* of not more than 3 -

(i) notwithstanding C1.9(a) and (b) and C2.6, timber framing may be used for -

(A) *external walls*; and

(B) *common walls*; and

(C) the floor framing of lift pits; and

(D) non-*loadbearing internal walls* which are *required* to be *fire-resisting*; and

(E) non-*loadbearing shafts*, except *shafts* used for the discharge of hot products of combustion; and

(F) spandrels or horizontal construction provided for the purposes of C2.6; and

(ii) notwithstanding Clause 3.1(d) of Specification C1.1, for *loadbearing internal walls* and *loadbearing fire walls* -

(A) timber framing may be used; and

(B) *non-combustible* materials may be used.

(b) A Class 2 or 3 building having a *rise in storeys* of not more than 4 may have the top three storeys constructed in accordance with (a) provided -

(i) the lowest *storey* is used solely for the purpose of parking motor vehicles or for some other ancillary purpose; and

(ii) the lowest *storey* is constructed of concrete or masonry including the floor between it and the Class 2 or 3 part of the building above; and

(iii) the lowest *storey* and the *storey* above are separated by construction having an FRL of not less than 90/90/90 with no openings or penetrations that would reduce the *fire-resisting* performance of that construction except that a doorway in that construction may be protected by a –/60/30 *self-closing* fire door.

(c) In a Class 2 or 3 building complying with (a) or (b) and fitted with a sprinkler system (other than a FPAA 101 D or FPAA 101 H system) complying with Specification E1.5, any FRL criterion prescribed in Table 3 -

(i) 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

(ii) for any non-*loadbearing internal wall*, need not apply if -

(A) it is lined on each side with 13 mm standard grade plasterboard or similar *non-combustible* material; and

(B) it extends -

(aa) to the underside of the floor next above; or

(bb) to the underside of a ceiling with a *resistance to the incipient spread of fire* of 60 minutes; or

(cc) to the underside of a *non-combustible* roof covering; and

(C) any insulation installed in the cavity of the wall is *non-combustible*; and

(D) 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; and

(E) any doorway in the wall is protected by a *self-closing*, tight fitting, solid core door not less than 35 mm thick.

4.3 Class 2 and 3 buildings: Concession

(a) In a Class 2 or 3 building with a rise in storeys of not more than 2 -

(i) notwithstanding C1.9(a) and (b), timber framing may be used for -

(A) external walls; and

(B) common walls; and

(C) the floor framing of lift pits; and

(D) non-loadbearing internal walls which are required to be fire-resisting; and

(E) non-loadbearing shafts, except shafts used for the discharge of hot products of combustion; and

(ii) notwithstanding Clause 4.1(e) of Specification C1.1, for loadbearing internal walls and loadbearing fire walls -

(A) timber framing may be used; and

(B) non-combustible materials may be used.

(b) A Class 2 or 3 building having a *rise in storeys* of not more than 2 may have the top storey constructed in accordance with (a) provided -

(i) the lowest *storey* is used solely for the purpose of parking motor vehicles or for some other ancillary purpose; and

(ii) the lowest *storey* is constructed of concrete or masonry including the floor between it and the Class2 or 3 part of the building above; and

(iii) the lowest *storey* and the *storey* above are separated by construction having an FRL of not less than90/90/90 with no openings or penetrations that would reduce the *fire-resisting* performance of that construction except that a doorway in that construction may be protected by a –/60/30 *self-closing* fire door.

(c) In a Class 2 or 3 building complying with (a) or (b) and fitted with a sprinkler system (other than a FPAA 101D or FPAA 101 H system) complying with Specification E1.5, any FRL criterion prescribed in Table 4 -

(i) for 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

(ii) for any non-*loadbearing internal wall*, need not apply, if -

(A) it is lined on both sides with 13 mm standard grade plasterboard or similar non-combustible material; and

(B) it extends -

(aa) to the underside of the floor next above if that floor has an FRL of at least 30/30/30 or is lined on the underside with a *fire-protective covering*; or

(bb) to the underside of a ceiling with a *resistance to the incipient spread of fire* of 60 minutes; or

(cc) to the underside of a *non-combustible* roof covering; and

(C) any insulation installed in the cavity of the wall is *non-combustible*; and

(D) any construction joints, spaces and the like between the top of the wall and the floor, ceiling or roof is smoke sealed with intumescent putty or other suitable material.

C

Appendix C - Example Calculations of Fire Test Loading for a Timber Stud Partition

Examples have been provided for two common end conditions to demonstrate the need to clearly define the end conditions and adjust the test load accordingly.

Example 1 - Bottom nail joint to timber plate upper pinned joint

Bottom nail joint to timber plate upper pinned joint

Design to AS 1720.1

MGP10 Timber studs 90mm x 45mm

b=45 mm; d=90mm, A_c = 4050mm^2

Noggings provided at approx. 750mm centres. Buckling expected about major axis.

Length of Stud between supports (L) – Taken as from pin joint to interface with the surface of sill plate = 2.936m.
Studs nailed to plates.
From Table 3.2:
Studs in light framing g_{13}= 0.9
Studs restrained at both ends in position only g_{13}=1.0
One end typical light framing detail other held in position only (pinned joint) therefore g_{13}=0.95 adopted
L_{ax} = L . g_{13} = 2.79m
S_3 =L_{ax} / d ≈ 31.0

Characteristic Stress for Compression parallel to grain (f_c') 18MPa	App H Table H3
Material Constant Seasoned Timber ρ_c=0.96	Table 3.3
ρ_c S ≈ 29.7	
Stability Factor k_{12} ≈ 0.227	For ρ_c S ≤10; k12 = 1.0 For 10 ≤ρ_c S ≤20; k_{12} = 1.5 – 0.05ρ_c S For ρ_c S ≥20; k_{12} = 200 / (ρ_c .S)^2
Φ = 0.7	Category 2 MGP from Table 2.1
k_1 = 0.57	Permanent and long-term imposed action from Table G1
k_4 = 1	Seasoned clause 2.4.2.3
k_6 = 1	No temp extremes in normal service Clause 2.4.3
Design capacity in compression parallel to the grain $N_{d,c}$ ≈ 6.6kN (ambient)	$N_{d,c}$ = φk_1 k_4 k_6 k_{12} f_c' A - Clause 3.3.1.1
Load duration independent ambient design capacity R_b = $N_{d,c}$ = 11.6 kN / Stud	k_1=1 for Load duration independent design capacity
LR_{fb} ratios of 0.5 adopted for general application.	Based on analysis of load combinations
Test Load = $N_{d,c}$ x R =11.6 x 0.5 ≈ 5.8kN / stud	Under fire conditions

Example 2 - Both ends nail joint to timber plates fixed to test frame that does not allow rotation

Both ends nail joint to timber plates fixed to test frame that does not allow rotation

Design to AS 1720.1

MGP10 Timber studs 90mm x 45mm

b=45 mm; d=90mm, A_c = 4050mm^2

Noggings provided at approx. 750mm centres. Buckling expected about major axis.

Length of Stud between supports (L) – Taken as from interfaces with the surface of sill and head plate = 2.91m.
Studs nailed to plates.
From Table 3.2:
Studs in light framing g_{13}= 0.9
L_{ax} = L . g_{13} = 2.91 x 0.9 m =2.62
S_3 =L_{ax} / d ≈ 29.1

Characteristic Stress for Compression parallel to grain (f_c') 18MPa	App H Table H3
Material Constant Seasoned Timber ρ_c=0.96	Table 3.3
ρ_c S ≈ 27.9	
Stability Factor k_{12} ≈ 0.257	For ρ_c S ≤10; k12 = 1.0 For 10 ≤ρ_c S ≤20; k_{12} = 1.5 – 0.05ρ_c S (c) For ρ_c S ≥20; k_{12} = 200 / (ρ_c .S)^2
Φ = 0.7	Category 2 MGP from Table 2.1
k_1 = 0.57	Permanent and long-term imposed action from Table G1
k_4 = 1	Seasoned clause 2.4.2.3
k_6 = 1	No temp extremes in normal service Clause 2.4.3
Design capacity in compression parallel to the grain $N_{d,c}$ ≈ 7.5 kN (ambient)	$N_{d,c}$ = φk_1 k_4 k_6 k_{12} f_c' A - Clause 3.3.1.1
Load duration independent ambient design capacity R_b = $N_{d,c}$ = 13.1 kN / Stud	k_1=1 for Load duration independent design capacity
LR_{fb} ratios of 0.5 adopted for general residential application.	Based on analysis of load combinations
Test Load = $N_{d,c}$ x R =13.1 x 0.5 ≈ 6.55 kN / stud	Under fire conditions

Appendix D - Evidence of Suitability for Fire-protected Timber

General Requirements

There are three components to the performance of *Fire-protected Timber* that 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).

In addition, for timber framed and lightweight construction where there are cavities within the elements of construction the following apply,

- any cavity insulation must be non-combustible
- internal cavity barriers must be provided.

Non-Combustible Fire-Protective Covering

Unless the NCC deems a material or element of construction to be non-combustible, non-combustible means:

- Applied to a material – not deemed combustible as determined by AS 1530.1 – Combustibility Tests for Materials.
- Applied to construction or part of a building – constructed wholly of materials that are not deemed combustible.

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 D1.

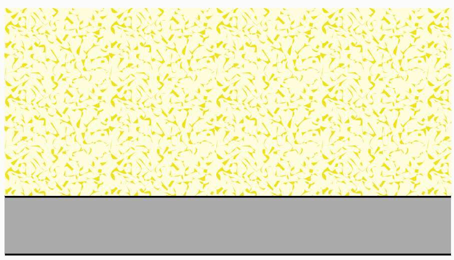
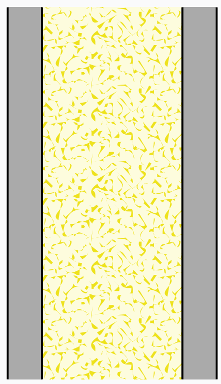
	
Multi-layer system – each layer must be non-combustible	Composite panels – each layer of the composite must be non-combustible
Commonly fire resistant board supporting non-combustible lightweight insulation used in ceilings protecting floors/beams	Commonly non-combustible lightweight insulating core between non-combustible durable facings used for external claddings

Figure D1: Example of multi-layered fire-protective coverings (all layers).

Clause C1.9(e) of the NCC allows the following materials, though combustible or containing combustible fibres, to be used wherever a non-combustible material is required:

- plasterboard
- perforated gypsum lath with a normal paper finish
- fibrous-plaster sheet
- fibre-reinforced cement sheeting
- 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
- sarking-type materials that do not exceed 1 mm in thickness and have a Flammability Index not greater than 5
- bonded laminated materials where:
  - each laminate is non-combustible
  - each adhesive layer does not exceed 1 mm in thickness
  - the total thickness of the adhesive layers does not exceed 2 mm
  - 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 are either permitted to be used in accordance with NCC Clause C1.9(e) or determined to be non-combustible by testing to AS1530.1. Appropriate *Evidence of Suitability* should therefore be a AS 1530.1 test report from an accredited testing laboratory or a determination that the fire-protective covering is one of the materials listed in C1.9(e).

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 Schedule 5.2(b) and (c) of the NCC.

Generally, Schedule A5.2(b) requires a prototype to be submitted to the Standard Fire Test (AS 1530.4), 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 an Accredited Testing Laboratory which:

- describes the method and conditions of the test and the form of construction of the tested prototype in full
- certifies that the application of restraint to the prototype complied with the Standard Fire Test;
- or differs in only a minor degree from a prototype tested under Schedule 5.2(b) and the FRL attributed to the building element is confirmed in a report from an Accredited Testing Laboratory which:
- certifies that the building element is capable of achieving the FRL despite the minor departures from the tested prototype; and
- describes the materials, construction and conditions of restraint which are necessary to achieve the FRL.

The option to use AS 1720.4 char-based calculation methods to determine the fire resistance is not permitted for *Fire-protected Timber.* This is because concerns were expressed with respect to the suitability of the AS 1720.4 approach for certain types of adhesives and connections forming parts of engineered timber products. The proprietary nature of *Massive timber* panel products and lack of standardisation of adhesives and other critical materials used in their construction at the time meant that there was insufficient data available at the time to demonstrate the suitability or otherwise of AS 1720.4.

Resistance to the Incipient Spread of Fire

Determine Applicable *Resistance to the Incipient Spread of Fire* Requirements

The *Resistance to the Incipient Spread of Fire* (RISF) as applied to fire protected timber elements 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 RISF requirements for massive *Fire-protected Timber* elements providing both the following additional criteria are satisfied.

- the minimum timber panel 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 dimension relates to the inherent fire resistance achieved when using a timber panel member. If the relaxation conditions are satisfied, the Modified Resistance to the *Incipient Spread of Fire* (MRISF) criteria are applicable.

Figure D2 shows the process for determining the applicable *Resistance to the Incipient Spread of Fire* requirements. The general requirement for Fire-protected Timber is a RISF of 45 minutes.

The relaxed requirements for *Massive timber* construction without voids and cavities is a MRISF that applies a higher interface temperature limit (300°C) and the time periods for which the temperature limit applies varies according to the application in accordance with Table D1.

Table D1: Modified Resistance to the Incipient Spread of Fire required performance for applications where criteria are relaxed (Massive timber construction without voids and cavities).

Application	**Modified *Resistance to the Incipient Spread of Fire* (MRISF)**
Inside a fire-isolated stairway or lift shaft	20 min
External walls within 1 metre of an allotment boundary or 2 metres of a building on the same allotment	45 min
All other applications	30 min

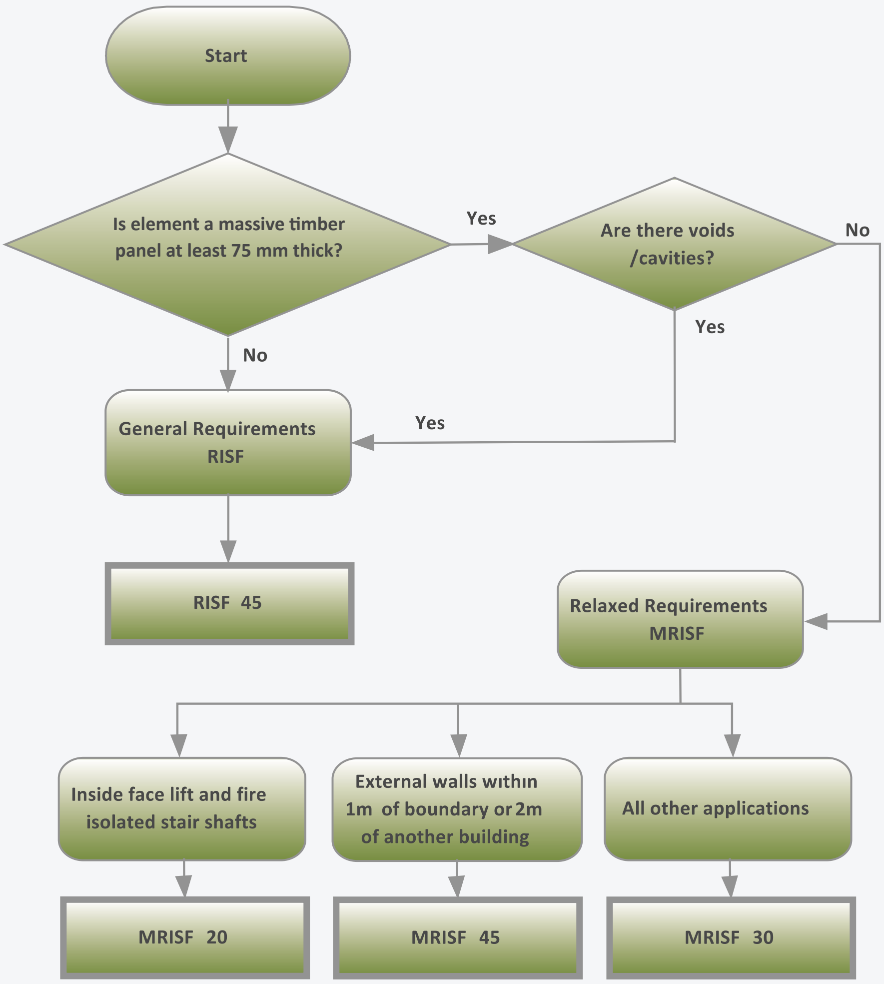


Figure D2: Determination of Resistance to the Incipient Spread of Fire acceptance requirements.

Evidence of Suitability Options for Resistance to the Incipient Spread of Fire

Three paths are permitted to demonstrate compliance with the RISF requirements;

- simultaneous determination during a full-scale fire resistance test
- smaller-scale fire resistance test (at least 1 metre x 1 metre 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 their FRLs but in many cases prior to 2016 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 fixed 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 C1.13a deems fire-protective grade plasterboard facings, if fixed in accordance with the requirements to achieve the required FRL of the element and of the required thickness, to also satisfy the requirements for *Resistance to the Incipient Spread of Fire* (RISF) or *Modified Resistance to the Incipient Spread of Fire* (MRISF). Table D2 shows the minimum requirements for plasterboard coverings.

Table D2: Fire-protective grade plasterboard coverings Deemed-to-Satisfy RISF requirements.

Requirements	Application	Performance criteria	Minimum DTS fire-protective grade plasterboard
General Requirements	All applications	RISF 45min	2 layers x 13 mm thick
Relaxed requirements for timber panels not less than 75 mm thick 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 metre of an allotment boundary or 2 metres 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

Resistance to the Incipient Spread of Fire (RISF) Test Procedures

The test procedure for determining the *Resistance to the Incipient Spread of Fire* (RISF) of horizontal elements during a full-scale fire resistance test is provided in Section 4 of AS 1530.4. Specification C1.13a 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 the standard heating conditions from the underside and fire-resisting 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 is specified.

Smaller-scale specimens (not less than 1 m x 1 m) can be used to retrospectively determine the RISF performance of a floor or wall system that has previously achieved the required FRL in a fire resistance test satisfying the minimum size requirements specified in AS 1530.4. This requirement is included to evaluate the "stickability" (retention) of fire protective coverings which generally require full-scale specimens to evaluate the sensitivity to differential expansion / shrinkage and reduction in mechanical performance, amongst other things.

For universal application of results the minimum cavity depth should be fire tested.

To determine the RISF, five thermocouples with insulating pads as prescribed in AS 1530.4 are fixed to the inner face of the fire-protective covering system. They are placed at approximately the centre and the centre of each quarter section as shown in Figure D3. When testing corrugated specimens, increase the number of thermocouples to six to provide an equal number of thermocouples at the maximum and minimum specimen thickness.

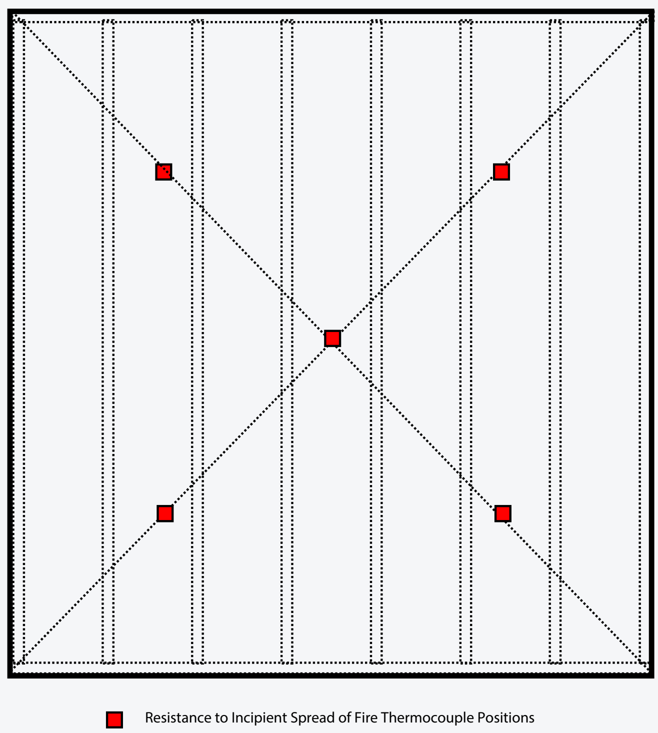


Figure D3: Elevation of a wall showing RISF thermocouple positions

Sections through typical specimen configurations are shown in Figure D4 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. If a wall or 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 (t/c) should be applied to the surface of the insulation as shown in Figure D4.

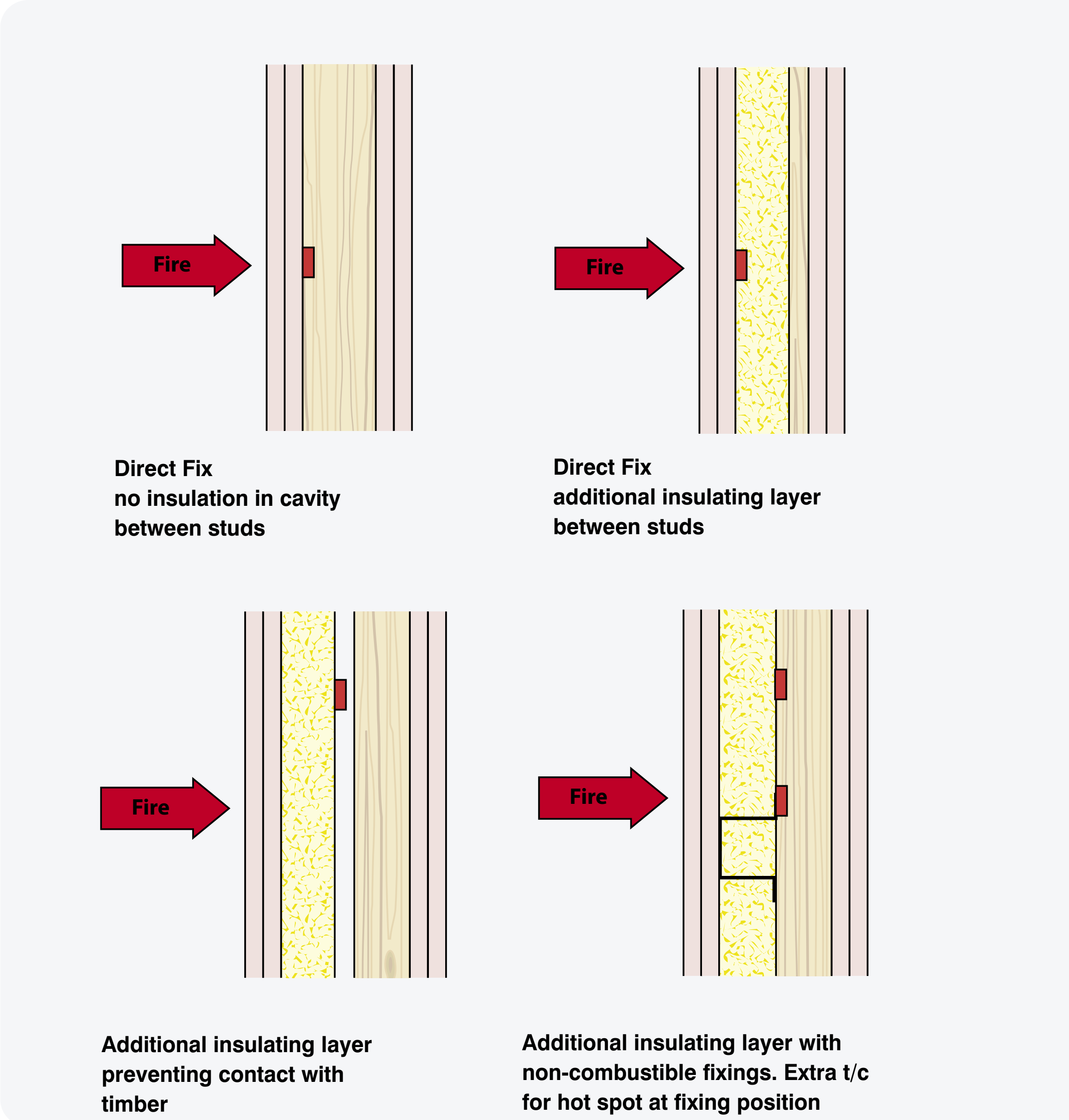
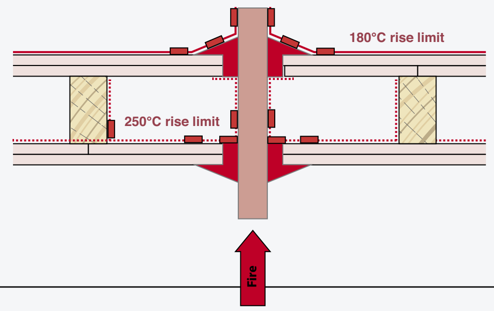


Figure D4: Resistance to the incipient spread of fire thermocouple positions for typical specimen configurations.

Failure in relation to the RISF 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 D5. Additional thermocouples are shown to allow the simultaneous determination of the FRL of the service penetration system.

<table>
<tr>
<td>Cable/metal pipe penetration protected with fire-resistant mastic.</td>
<td>
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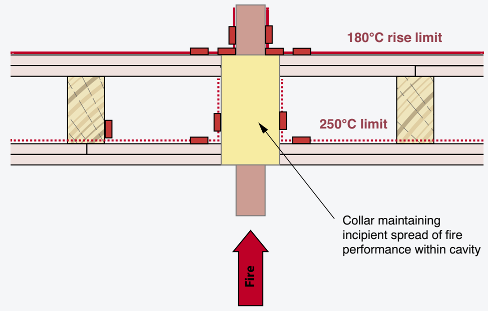
<td>Plastic pipe protected by insulating collar system.</td>
<td>
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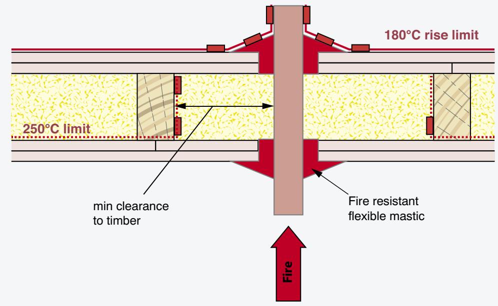
<tr>
<td>Cable/metal pipe penetration protected with fire resistant mastic and non-combustible cavity infill.
The critical interface for RISF for the service penetration system is the surface of the insulation where it is in contact with timber elements. Note: plasterboard surface is the critical surface for determining the RISF of the wall system</td>
<td>
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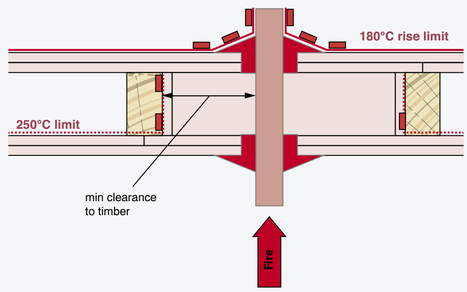
<tr>
<td>Cable/metal pipe penetration protected with fire-resistant mastic and cavity lined with non- combustible board.
The critical interface for RISF for the service penetration is the surface of the lining board where it is in contact with timber elements.</td>
<td>
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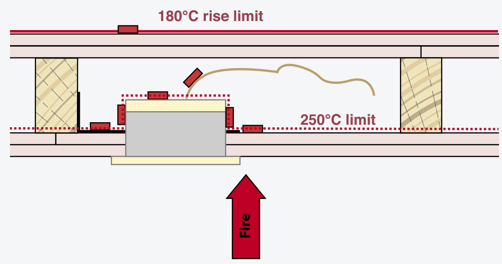
<tr>
<td>Proprietary GPO outlet protection system.
Note: Thermocouples applied to cable surface connected to the GPO, on fixing bracket and adjacent element.</td>
<td>
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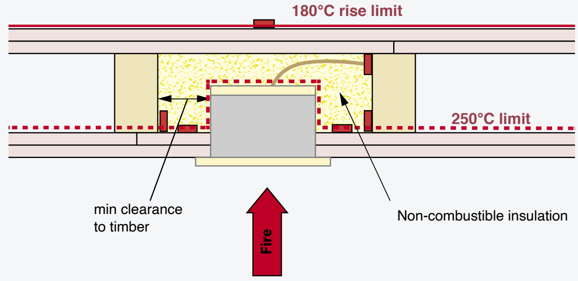
<tr>
<td>GPO outlet with non-combustible cavity infill protection.
The critical interface for RISF is the surface of the insulation where it is in contact with timber elements. Note: plasterboard surface is the critical surface for determining the RISF of the wall system</td>
<td>
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</table>

Figure D5: Typical thermocouple positions for determining the RISF of service penetrations.

The thermocouples positions must satisfy the following requirements:

- At not less than two points about 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 two thermocouples about 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 down lights).

Failure in relation to the RISF is deemed to occur for the service penetration when the maximum temperature of the thermocouples described above exceeds 250°C.

Modified Resistance to the *Incipient Spread of fire* (MRISF) Test Procedures

The MRISF is applicable to *Massive timber* panels having a thickness not less than 75 mm if there are no voids/cavities through which fire and smoke can spread. The MRISF, amongst 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 C1.13a 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 1m x 1m) 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.

Testing to evaluate the MRISF performance must measure the temperatures at the following locations:

- at joint positions in the protection systems
- at least 200 mm from any joint
- at any other locations if, in the opinion of the Accredited Testing Laboratory, the interface temperature may be higher than the above positions.

Temperatures at each of these locations must be measured by a minimum of two thermocouples complying with Appendix C1 and Section 2 of AS 1530.4 as appropriate.

Where the fire protective covering is not in contact with the timber (e.g., multi-layer system), the surface of the fire-protective covering is deemed to be the interface.

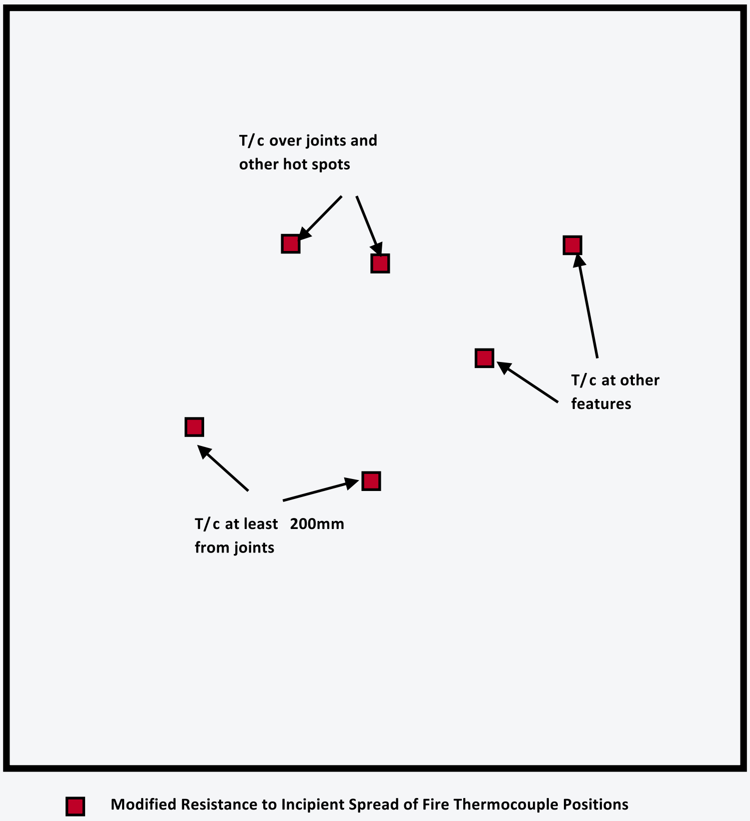


Figure D6: Elevation of a wall showing modified RISF thermocouple positions.

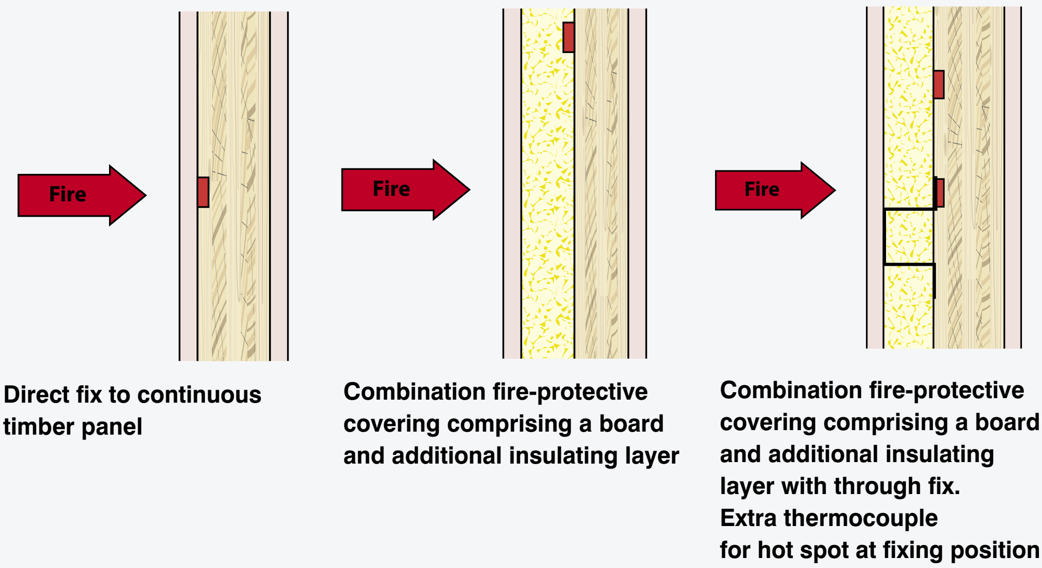


Figure D7: Modified RISF thermocouple positions for typical specimen configurations.

Failure in relation to the MRISF is deemed to occur when the maximum temperature of the thermocouples described above exceeds 300°C.

Smaller scale specimens 1 metre x 1 metre 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 D8.

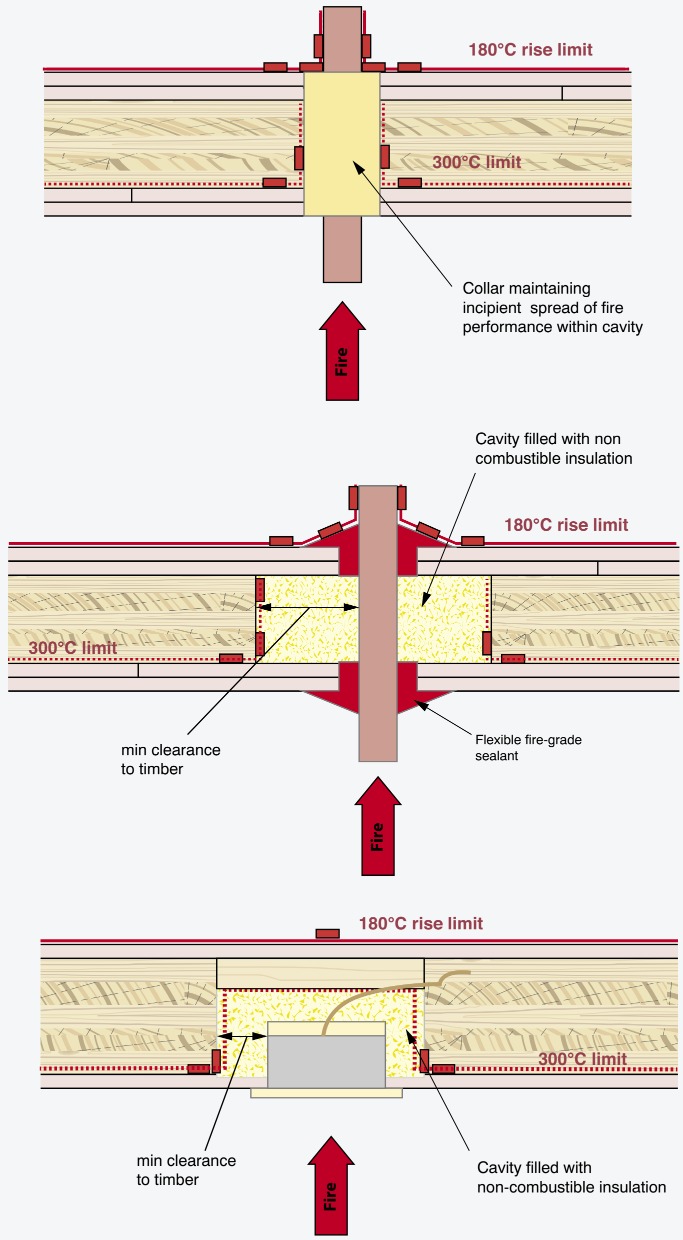


Figure D8: Typical thermocouple positions for determining the MRISF of service penetrations.

Evidence of Suitability for Cavity Barriers in *Fire-Protected Timber* Construction

Specification C1.13 of the NCC sets out the requirements for cavity barriers in *Fire-protected Timber* re-protected timber construction. The following compliance options are provided for cavity barriers:

- the cavity barrier system must achieve the FRLs specified in Table D3 when mounted in timber elements
- comprise timber of minimum thickness as specified in Table D3 and with density equal to or greater than the structural timbers in the proposed application 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 D3 or
- for cavity barriers fitted around doors and windows, steel frames are also Deemed-to-Satisfy the requirements for cavity barriers provided that 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 D3: Cavity barrier requirements for Fire-protected Timber.

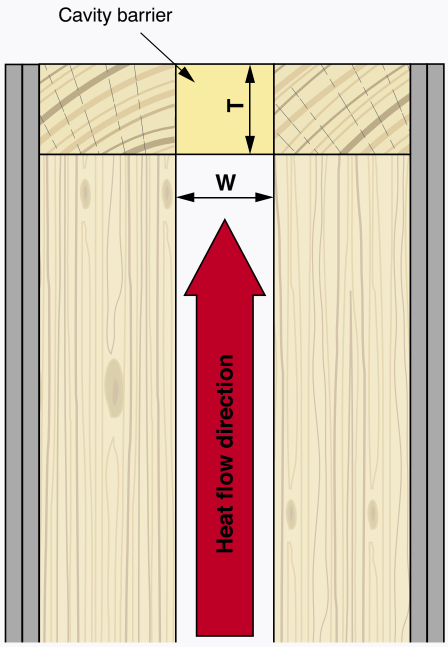
Requirements	FRL required for element cavity barrier is fitted to (minutes)	
	–/90/90 or less	**greater than –/90/90**
Cavity Barrier Required FRL – minutes	–/45/45	–/60/60
Timber required minimum thickness	45 mm	60 mm
Mineral wool required minimum thickness	45 mm	60 mm

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 top plate of a double stud partition (Detail A of Figure D9) 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.

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-resisting wall. This configuration is shown as Detail B in Figure D9. For this scenario, the heat flow is from the occupied area of the building through the framing to the cavity. In the Figure, the thickness dimension is identified as 'T'.

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 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 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 with a nominal density at least equal to the tested timber.

Detail A
Cavity Barrier at the Head of a double stud partition



Detail B
Cavity Barrier around door opening

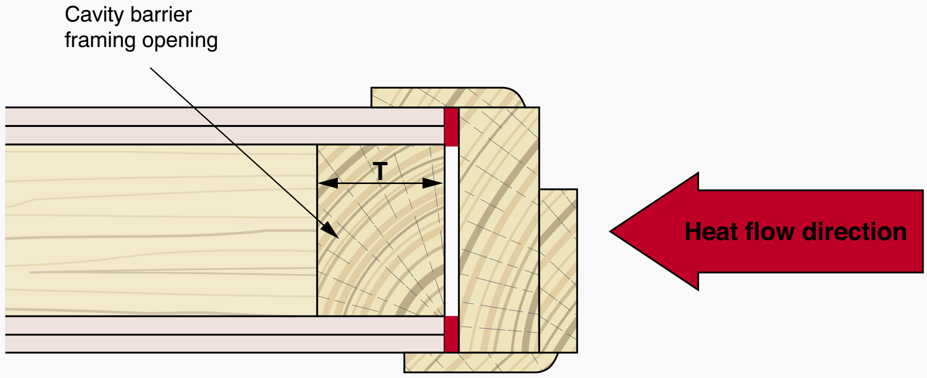


Figure D9: Heat flow direction for cavity barriers.

Typical test configurations are shown in Figure D10. The selection of the test configuration(s) depends on how the cavity barrier will be mounted. If it is symmetrical (e.g. fitted at the mid-depth of a timber member), 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 an Accredited Testing Laboratory should state the field of application for the cavity barrier based on the test results.

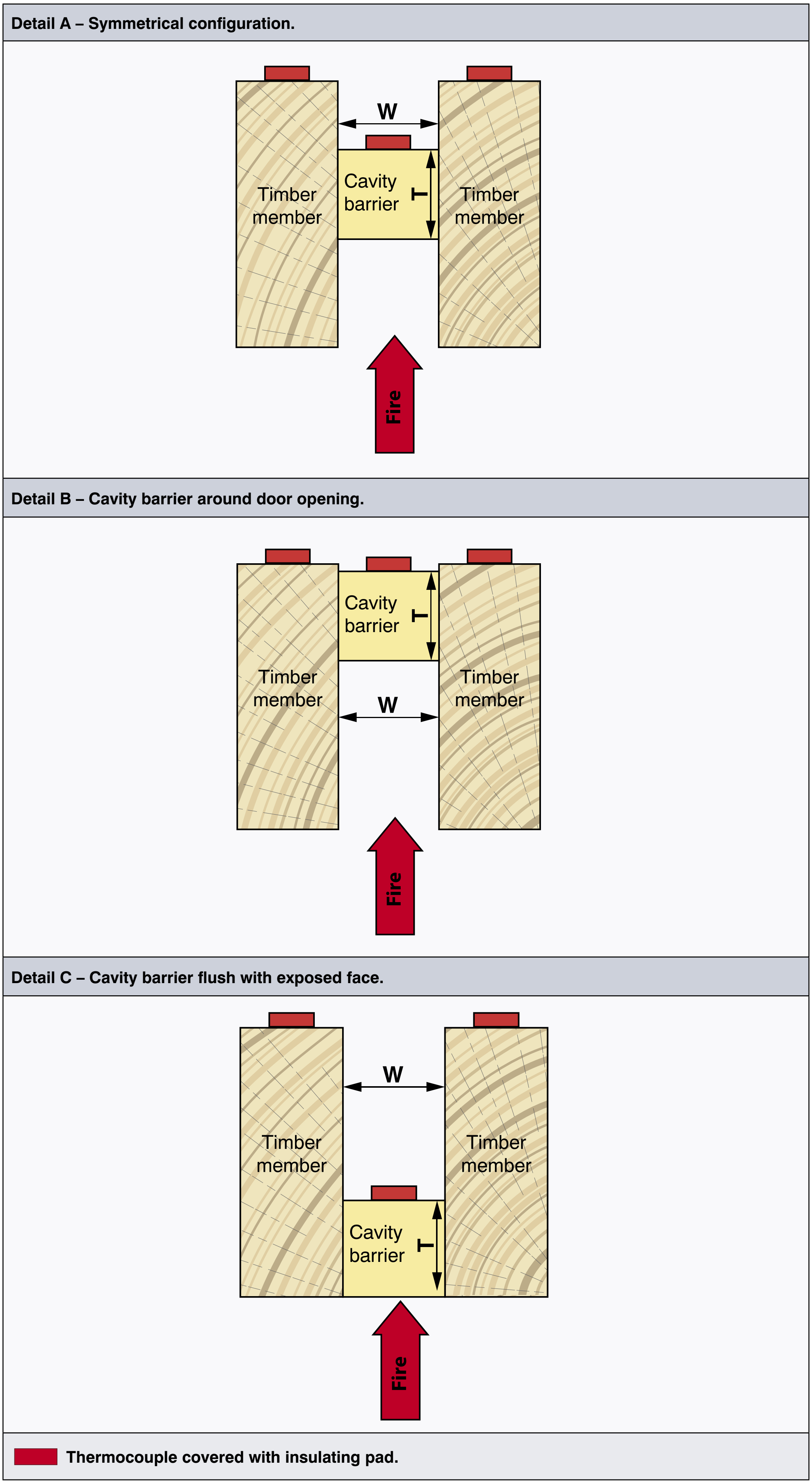
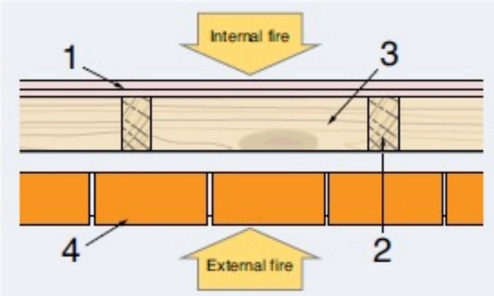


Figure D10: Typical cavity barrier test configurations.

E

Appendix E – Example Data Sheet Identifying Evidence of Suitability

External Brick Veneer Timber framed wall system



1 Fire protective grade plasterboard, 2 x 13 mm thick

2.Timber framing in accordance with Evidence of Suitability

3 Cavity. – Cavity insulation may be required to achieve sound ratings and R –value (insulation must be non-combustible)

4 Outer brick veneer 90 mm thick

Typical Performance

Fire-protected timber	FRL90/90/90: RISF45: NC
Sound transmission and insulation	R_w 50: R_w+C_{tr} 50
Thermal resistance	R Value 3.3 m^2K/W
Damp and weatherproofing	NCC performance requirement FP1.4
Structural tests	NCC specification C1.8 Clause 3.4

Evidence of Suitability

Fire-protected timber:	
Internal Fire Exposure	FRL Test or assessment report from an Accredited Testing Laboratory complying with NCC A5.4 – (Lab XYZ Report Ref 123) RISF – 45 (NCC Spec C1.13a DTS)
External Fire Exposure	FRL Test or assessment report from an Accredited Testing Laboratory complying with NCC A5.4 or design in accordance with AS 3700 RISF – 45 (AS 3700 design for insulation or test or assessment report from an Accredited Testing Laboratory)
Non-combustibility	Plasterboard NCC C1.9(e)(i) DTS Fire-protected timber NCC C1.13 Concession Cavity Insulation AS 1530.1 test Brickwork – NCC C1.9 / C2D10(4) n iii (planned introduction in 2022) DTS

Sound Transmission and Insulation No NCC requirement for external walls in NCC but commonly specified for inner city locations. Report from a laboratory or acoustics engineer stating performance achieved.

Thermal Resistance R-Value Report complying with NCC Clause A5.2

Weatherproofing Statement of compliance with relevant requirements of AS 3700 and report confirming applicability of AS 3700 – complying with NCC Clause A5.2.

Structural tests for lightweight construction Report complying with NCC Clause A5.2 expressing results of tests in accordance with NCC specification C1.8.

Primary Distributors Plasterboard Supplier xyz

Note: The above is an example of how summaries can be developed to identify necessary Evidence of Suitability for fire protected timber elements. A document similar to the above could be included in a product technical statement from a manufacturer. Selection of systems that are fit for purpose and the provision of Evidence of Suitability to the satisfaction of the Appropriate Authority is the responsibility of the designers and product suppliers. Forest and Wood Products Australia Limited (FWPA) and the authors of this Guide make no warranties or assurances with respect to the fitness for purpose of the systems described in this Guide.

F

Appendix F References

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Technical Design Guide 18
Alternative Solution Fire Compliance - Facades

This guide is under review - placeholder page only.

Technical Design Guide 19
Alternative Solution Fire Compliance - Internal Linings

This guide is under review - placeholder page only.

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Fire Precautions During Construction of Large Buildings

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Contents

1 Role of this Document

The role of this document is to provide information to help the broad range of people and organisations with responsibilities for fire safety on a construction site to reduce the risk from fire.

The information applies to the design and planning stages as well as the actual construction phase, and many hazards can be addressed by good design and planning before they become an issue.

Construction projects can include demolition, alterations, renovations, repair and maintenance as well as new buildings.

Much of the content of this Guide can be incorporated in:

- design documentation (including design reports);
- building permits;
- the Workplace Health and Safety (WHS) Plan for the site, which may refer to a separate Fire Safety Plan;
- safe work methods; and
- hot work permit systems.

It is critical that all parties involved in a project work together to ensure that the fire risk is minimised and that everyone on a construction site is aware of their responsibilities.

This Guide does not apply to the completed structure. Minimum community building standards for fire safety in completed buildings are mandated by State and Territory Acts and Regulations that normally require compliance with the National Construction Code (NCC), among other things. WHS legislation may require additional fire precautions to be implemented, such as evacuation plans and emergency procedures.

Any recommendations in this Guide do not negate the need to comply with all relevant legislation and contractual requirements.

2 Relevant Legislation

Regulation of matters relating to fire safety and occupational health and safety (OHS) and workplace health and safety (WHS) is the responsibility of the States and Territories of Australia. Substantial efforts have been made to obtain a nationally consistent approach through the National Construction Code (NCC)[1] and the Model Workplace Health and Safety Acts[2]. At the time of writing, all States and Territories adopt similar approaches but there are still variations in the detailed legislation and administration.

Building Acts and Regulations in the States and Territories generally require building surveyors/certifiers to ensure compliance with the National Construction Code (NCC). The NCC Volume One (EP1.5)[3] requires suitable means to be installed in a building under construction to allow initial firefighting by construction workers and for the fire brigade to undertake an attack on the fire. The related Deemed-to-Satisfy provisions included in Clause E1.9[4] are limited to providing fire extinguishers in buildings up to an effective height of 12 metres. For buildings above that height, hydrants, hose reels and booster connections are also required. Where a Performance Solution that meets performance requirement EP1.5 is proposed, most State regulations require the matter to be referred to the relevant fire authority.

Under WHS legislation, a person conducting a business or undertaking (PCBU), has a general duty to ensure the health and safety of employees at work and members of the public on or adjacent to the site. Note: A 'person' may be an organisation or an individual.

While fires on construction projects are not common, they do pose a significant risk to both human safety and construction programs, so the risk needs to be managed.

WHS legislation places additional responsibilities on principal contractors undertaking construction work. These include preparing a written WHS management plan, requirements for signage and obligations to ensure compliance with other regulations at the workplace.

It also requires persons who conduct a business that commission construction work to consult with the designer, and requires designers of structures to provide a written report regarding health and safety. In relation to fire safety, the designer could be a fire safety engineer or, if Deemed-to-Satisfy approaches are adopted, the architect or a regulatory consultant.

Persons conducting a business are required to control risks associated with construction work and impose duties around safe work method statements and liaison with other persons as necessary.

Under the WHS legislation, there is an obligation on all the parties involved to address issues such as fire prevention, emergency procedures and evacuation, and other mitigation methods in addition to firefighting as defined in the NCC Building Code of Australia.

There is additional complexity when buildings are partially occupied while building works are being undertaken. In such cases, building owners and the employers of the people occupying the building also have duties to fulfil under WHS regulations.

This Guide provides practical fire safety guidance for buildings during construction and has been created as a tool to help people meet their obligations. Because of the nature of WHS legislation, this Guide does not negate the need to undertake risk assessments where appropriate and develop mitigation measures to address site-specific issues.

3 Definitions

Large projects (buildings):
Construction relating to Class 2 to 9 buildings as defined in the NCC, where the value of the building or proposed building exceeds $5 million. Note: *A contractor may have a relatively small contract value but if the works are being undertaken in a large, existing building the work should be classified as a large project.*

Fire resisting coverings:
Coverings applied to elements of construction to increase the fire resistance of the element of construction. Examples include covering systems protecting timber or structural steel (eg. fire-rated plasterboard). The protection required depends on the application.

Fire preventative coverings:
Coverings, screens or treatments to combustible materials/elements of construction that reduce the risk of ignition.

Examples include:

- fire retardant treatments
- fire resisting coverings
- non-combustible sheeting.

The performance required depends on the application.

Exposed combustible materials:
Combustible materials that are exposed or with coverings that do not provide adequate protection from expected fire sources such that the combustible core can be readily ignited.

4 Fire Safety Plan

A site may have a Fire Safety Plan incorporated in its Workplace Health and Safety (WHS) Plan or a separate Fire Safety Plan referenced by the WHS Plan.

Generally, the principal contractor undertaking construction is responsible for developing the WHS plan, including a Fire Safety Plan, which may be based on detailed risk assessments.

The plan should include:

- the organisation structure and responsibilities for fire safety;
- arrangements for providing and recording fire safety training/induction given to site personnel and visitors, including required actions in case of fire;
- risk assessments and designer reports requiring specific fire safety measures;
- inclusion of fire safety requirements in Safe Work Methods (SWMs);
- adequate means for evacuation;
- emergency procedures;
- fire prevention measures, including:
  - security requirements
  - control of ignition sources
- hot works permits/regulations;
- electrical supplies and equipment;
- compliance with ‘no smoking’ legislation;
- cutting;
- plant equipment and vehicles;
- prohibition of open fires;
  - control/reduction of combustible materials;
- flammable liquids and gases;
- stored and waste materials disposal;
- combustible façade and building materials;
- fire brigade access, facilities and coordination;
- evacuation plan and procedures for alerting the fire brigade;
- fire protection provisions:
  - fire extinguishers
  - hydrants, hose reels and water supplies
  - automatic fire sprinklers
  - automatic fire detection and alarm systems
  - temporary emergency lighting
  - compartmentation
  - lining materials
  - structural adequacy and mitigation measures prior to application of fire protection
- separation from adjacent buildings and other hazards:
  - temporary buildings and accommodation
  - on-site storage facilities
  - adjacent permanent structures
- special provisions if work is being carried out in occupied buildings; and
- bushfire safety requirements if appropriate.

5 Fire Prevention

5.1 Fire Safety Awareness, Training and Compliance Monitoring

All people working on or visiting the site should be made aware of the importance of fire prevention and the content of the Fire Safety Plan, including what to do in the event of fire, emergency procedures, location of assembly points and good housekeeping practices.

Training in relation to the use of portable firefighting equipment, safety precautions for those undertaking hazardous operations, and the site-specific emergency procedures must be provided appropriate to the role of the individual.

Records should be kept of fire safety training and inductions given to site personnel and visitors.

5.2 Security

Security is required on a construction site for many purposes. Arson is the single largest cause of fires on building sites and it plays a key role in fire prevention.

The Fire Safety Plan should identify the required security measures, which may include:

- erecting secure fencing around the perimeter of the site;
- securing access points such as entries to the construction zone during refurbishment of an occupied building;
- employing 24-hour security guards on larger sites supported by CCTV;
- storing combustible materials, such as flammable liquids and gases, and potential ignition sources in secure areas to limit access to materials that could be used to start a fire;
- illuminating the site so that unauthorised people on the site can be easily identified; and
- installing intruder alarms in temporary buildings and storage areas as appropriate.

It can be beneficial for security staff to be trained in the use of portable extinguishers, particularly if they are on site outside normal working hours.

5.3 Control of Ignition Sources

5.3.1 Hot Works

Hot works include any activities that could initiate fires or explosions such as:

- cutting and grinding;
- welding, brazing and soldering;
- thermal spraying;
- use of oxyacetylene torch or blow torch; and
- installation of heat-applied materials.

Cutting/welding too close to combustibles is the second most common cause of fires after arson.

As far as reasonably practicable, activities involving hot works should be avoided. A permit system should be implemented where they cannot be avoided. The system should incorporate, as a minimum, the following features:

- Requirements for written permission (a permit) to be obtained prior to commencement of hot works.
- Hot works permits must be specific to a location, activity and work period and must not provide blanket coverage for more than one location activity or work period.
- An inspection of the hot works area before work begins to ensure that:
  - combustibles have been moved or are adequately protected;
  - appropriate fire extinguishers are on hand, fully charged and operable;
  - evacuation paths are available.

- A suitably trained and equipped person is assigned to fire watch during the hot works and for an appropriate period after works has been completed.
- Inspection of hot works areas at the end of the day and by security staff if on site and it is reasonably practicable and safe to access the area.
- There are means for communicating an alarm.

The requirement for a hot works permit and other precautions should be incorporated in Safe Work Methods (SWMs) for each type of hot works, based on the outcomes of a risk assessment or industry standard.

5.3.2 Electrical Supplies and Equipment

The use of electrical equipment and supply systems can be an ignition source during construction and care is required in order to minimise this risk. Consideration should be given to the following:

All electrical systems and equipment, including temporary installations, must be installed and maintained in accordance with relevant regulations.

All portable electrical devices and extension leads must be regularly inspected and tagged in accordance with State regulations.

Remove any faulty or damaged equipment from use immediately and label it accordingly.

Securely fasten any equipment that operates at surface temperatures exceeding 75°C to prevent hot parts of the equipment coming into contact with combustible materials.

Equip fragile components, such as temporary lights, with guards to prevent accidental damage where they are exposed to the risk of an impact.

Low voltage equipment should be used where practicable.

Remove temporary wiring immediately after completing the job it was installed for.

5.3.3 Smoking Materials

Smoking materials are a significant ignition source of fires on construction sites. Smoking restrictions should be applied throughout a construction site because hazardous materials, such as flammable gases, may be used in open as well as enclosed areas.

If designated smoking areas are to be provided on or adjacent to a construction site, a specific risk assessment should be undertaken. Smoking areas should be constructed of non-combustible materials and be separated from buildings by at least six metres (or more if determined necessary by a risk assessment). Provide safe receptacles for smoking materials.

Smoking restriction zones must be clearly identified, signposted and strictly enforced.

The risk of smoking materials being discarded around the perimeter of the site should be considered and, if the risk is significant, precautions should be implemented. These may include providing hoardings constructed from fire preventative coverings.

5.3.4 Open Fires/Waste Fires

Open fires, including the burning of waste materials, should be prohibited on the construction site. Combustible waste materials should be regularly removed from the site.

5.3.5 Plant Equipment and Vehicles

Locate plant equipment and vehicles so that their exhausts discharge, as far as practicable, away from combustible materials.

Prevent combustible materials coming in contact with hot surfaces or being close to hot surfaces such as flues/exhaust pipes.

Fuel storage and service areas should not be located within structures under construction, alteration or demolition.

Safe Work Methods (SWMs) should be prepared for refuelling activities.

Avoid the use of temporary heating equipment as far as reasonably practicable. Where it is to be used, undertake risk assessments.

The temporary heating equipment should, as a minimum, comply with relevant regulations and be installed, used and maintained in accordance with the manufacturer's instructions. The outcomes of the risk assessment may require additional precautions such as:

- specification of separation distances from combustible materials;
- requirement for personnel to be in attendance when the heater is running;
- restraining the heating device to minimise the risk of the appliance being knocked over or being incorrectly located; and
- regular inspections.

5.4 Control of Combustible Materials

5.4.1 Stored and Waste Materials

Remove combustible waste materials, dust and debris from the building and its immediate vicinity at the end of each shift or as soon as practicable.

Store combustible materials before its disposal as far from buildings as reasonably practicable.

Store materials susceptible to spontaneous ignition, such as oily rags, in clearly labelled non-combustible containers and remove them from site as soon as practicable.

Unless specific items of vegetation are planned to be retained, all dry vegetation should be removed from larger sites for a distance of 20 metres from buildings and structures under construction and work areas.

5.4.2 Storage of Combustible Building Materials

As far as possible, program the delivery of combustible materials to minimise the time they are stored on site.

Where significant volumes of combustible building materials are to be stored on site, they should be stored in a secure area at least 10 metres away from any buildings or partially constructed buildings and any location where hot works are undertaken.

Where there are no reasonably practicable alternatives and combustible building materials have to be stored within or close to the building under construction, the area used for storage should:

- have controlled access;
- not be in an area where hot works are being carried out;
- be in either an area covered by the site fire detection system or included on the route of regular fire checks;
- have firefighting equipment close by; and
- be protected from ignition sources where reasonably practicable by fire preventative covers (e.g. fire retardant, fire resistant, or non-combustible sheeting).

5.4.3 Exposed Combustible Materials During Construction

During the construction process, combustible materials may be temporarily exposed in locations such as the façade or as parts of wall or ceiling linings. Typical examples include:

- shade cloths, tarps and other covering around scaffolding, separating work areas and around the site perimeter;
- combustible façade materials; and
- timber framing.

Once the building is completed, these materials may not present a hazard because:

- they may have been removed from the site;
- fire preventative coverings or treatments may have been applied; or
- fire protective measures may have been installed, such as automatic sprinkler systems or compartmentation.

During the construction phase, if a risk assessment determines that the volume of exposed combustible materials is significant, additional precautions may be required.

In determining the need or extent for mitigation methods, the risk assessment should consider the proximity of the incomplete building to surrounding buildings, as well as fire safety within the site.

The following are examples of typical additional mitigation measures that could be considered.

Shade cloths and tarps and other temporary coverings should be fabricated from non-combustible materials, or fire retardant materials, where reasonably practicable, so as to minimise the risk of fire spread. The NCC Volume One[5] requirements for lining materials may form appropriate controls.

For buildings of three or more storeys, where the construction is predominantly of combustible construction, one or more of the following additional controls may be specified:

- Exposed combustible materials should be progressively clad with fire preventative coverings so that the number of storeys with significant exposed combustible materials is limited to two below the current construction level.
- If an automatic fire sprinkler system is to be provided, the sprinkler system should be progressively commissioned so that the number of unprotected storeys with significant exposed combustible materials is limited to two below the current construction level.
- Early installation of permanent or temporary fire compartments can limit fire spread in the event of an uncontrolled fire. Protection of door openings, windows, shafts and service penetrations need to be addressed.
- A temporary alarm system may need to be provided and evacuation procedures modified to address the expected rate of fire spread.
- Separation distances or fire barriers are needed between adjacent buildings and the building under construction appropriate to the fire hazard.

Risers should be installed progressively as construction is undertaken. Hydrants and hose reels required by the National Construction Code for the completed building must be progressively commissioned, as soon as reasonably practicable, on all levels of a building under construction.

The NCC Deemed-to-Satisfy provisions[6] require the following:

"After the building has exceeded an effective height of 12 metres.

(i) The required fire hydrants and fire hose reels must be operational in at least every storey that is covered by the roof or floor structure above except the two uppermost storeys and

(ii) any required booster connections must be installed."

5.4.4 Flammable Liquids and Gases

The storage and use of flammable liquids and gases require specific safety measures that address the risks of use in confined spaces and potential explosions, in addition to normal fire risks. Refer to the relevant State or Territory WHS legislation and guidelines that address the use of these substances and necessary precautions. This category includes common fuels (e.g. petrol and LPG) and acetylene used for cutting purposes. Typical requirements are provided in the Model Health and Safety Regulations[7]. Some (but not all) of the main mitigation methods applicable to fire safety are:

- instruct and train workers in the storage and handling of dangerous goods;
- keep storage of flammable liquids and gases to a minimum;
- store flammable liquids and gases in clearly labelled containers/cylinders compliant with Australian Standards in secure areas (preferably an open compound as far as practicable from the building under construction and work areas);
- provide clear signage identifying the materials being stored and prohibiting smoking, naked flame, hot works and the use of mobile phones;
- keep flammable liquid containers and tanks closed when not in use;
- segregate storage of flammable liquids and gases from materials that could intensify the fire or present a toxic hazard such as oxygen acetylene and chlorine;
- properly remove flammable materials before work is carried out on an empty container or vessel; and
- consider proximity to flammable liquids and gases in hot work risk assessments.

5.4.5 Waste/Garbage Chutes

If waste chutes are to be provided, where practicable they should be constructed of non-combustible materials and be located outside the building envelope.

The accumulation of combustible materials close to the chute should be minimised as far as practicable.

6 Fire Brigade Intervention and Emergency Procedures

6.1 Liaison with Fire Authorities

Regular liaison with the fire brigade is important so that it has knowledge of a site before a fire emergency, which will allow a more effective response. An initial site plan should be prepared and a process for updated drawings to be available in a fire emergency should be agreed.

The site plan should include:

- fire brigade access points to the site;
- any special provisions for firefighting activities;
- emergency escape routes and stairs;
- positions of hydrants and hose reels that are operative;
- location of booster connections;
- any other operative fire safety systems that have been provided;
- locations of assembly points and registers of persons currently on the site; and
- details of temporary accommodation and storage areas including location for storage of hazardous items such as flammable liquids, gas cylinders, etc.

The fire brigade should also be made aware of any performance solutions that could affect firefighting operations.

6.2 Water Supplies

The construction program should be planned, as far as reasonably practicable, to maintain adequate firefighting water supplies at all times throughout the site.

Australian Standards such as AS 2118[8], AS 2419[9] and AS 2441[10] may provide useful benchmarks for water supplies.

Regularly update the fire brigade on the hydrants and hose reels that are operational and of any potential or actual interruptions to the water supplies.

If the firefighting water supplies are interrupted:

- prohibit hot works;
- notify site workers; and
- undertake risk assessments to determine any additional actions that should be undertaken while firefighting water may be limited.

6.3 Fire Brigade Access

Maintain clear and unobstructed fire brigade access to the site and buildings at all times and notify the fire brigade immediately of any changes or restrictions to the access points.

If practicable, significant changes to the access to the site should be discussed with the fire brigade before being implemented.

6.4 Emergency Procedures

Written emergency procedures must be displayed in prominent locations and given to all employees and visitors on site. Typically, they should include:

- emergency contact details for key personnel who have specific roles or responsibilities under the emergency plan; for example fire wardens, floor wardens and first aid officers;
- contact details for local emergency services; for example police, fire brigade and poison information centre;
- description of the mechanisms for alerting people at the workplace to an emergency or possible emergency, for example siren or bell alarm;
- evacuation procedures including arrangements for assisting any hearing, vision or mobility-impaired people;
- map of the workplace illustrating the location of fire protection equipment, emergency exits and assembly points;
- triggers and processes for advising neighbouring businesses about emergencies;
- post-incident follow-up process, for example notifying the regulator, organising trauma counselling or medical treatment; and
- procedures for testing the emergency plan including the frequency of testing.

Additional guidance can be obtained from Safe Work Australia, State Safety Authorities and AS 3745-2010[11] *Planning for emergencies in facilities*.

Instruct nominated personnel, such as the security guards, to open gates or barriers and provide ready access to the site for the fire brigade in the event of an emergency or their other visits to the site.

Assembly points should be clearly identified.

Clear signs must be provided and maintained in prominent positions indicating the locations of fire brigade access routes, escape routes, positions of dry riser inlets and the fire extinguishers provided for use by trained staff. Signs should be reviewed regularly and replaced or repositioned as necessary.

7 Fire Protection and Egress Provisions

7.1 General

When the following fire protection services are required to be provided in the completed building, the project should be planned to achieve their installation and operation as soon as reasonably practicable:

- Fire stairs, including fire-resistant walls.
- Fire compartment boundaries, including fire doors, penetration seals and general protection of other openings. These should be completed progressively throughout a construction project to minimise fire spread in the event there is a fire during construction. Where the provision of fire compartments is critical to fire safety during construction, temporary coverings of openings should be provided while ensuring exit paths are not compromised.
- Fire protective materials to structural steel and fire preventative coverings over combustible construction if required.
- Automatic fire sprinkler systems and other automatic suppression systems. Where automatic fire sprinkler systems are required to be installed in a new building, there are significant advantages in progressively bringing the sprinkler system into service on each floor level. This approach is particularly effective in buildings where the design strategy relies on a sprinkler system to supplement fire separations (e.g. waiving requirements for spandrels or reducing FRLs) or controlling fire spread when combustible materials are exposed during construction.
- Automatic detection and alarm systems.

7.2 Temporary Alarm Systems

Where it is impractical to commission the permanent automatic detection and alarm systems during construction, an alternate means of warning of fire and other emergencies must be established to allow staff to raise an alarm across the site if a fire is detected and to alert the fire brigade. Manual devices may be utilised provided that:

- they are distinctive and clearly audible above background noises in all areas;
- all staff and inducted visitors are trained/instructed so that they can recognise the fire/emergency alarm and understand what action to take; and
- the devices are distributed throughout the site and staff are trained in their use.

Telephone systems can be used to alert the fire services if the emergency procedures adequately specify responsibilities for alerting the fire brigade and emergency numbers are prominently displayed together with the site address. Emergency phones should be located at strategic points and clearly identified.

7.3 Means of Egress

Construction programs should be planned to ensure that adequate paths of travel to exits and fire exits are provided at all times, taking into account the number of people, activities being undertaken and occupant capabilities.

Regular checks should be undertaken to ensure they are maintained clear of obstructions and provided with clear signage. Typically, these should be undertaken daily or weekly, depending on the risks associated with the site. The frequency should be increased if significant hazards such as blocked exits are observed.

7.4 Fire Extinguishers

In accordance with the NCC Deemed-to-Satisfy provisions[12] at least one fire extinguisher to suit Class A, B and C fire risks and electrical fires must be provided at all times on each storey adjacent to each required exit, or temporary exit or stairway. Refer to AS 2444[13] for further details relating to the fire risk classification and selection of extinguishers.

In addition, extinguishers should be provided for fire watch activities while hot works are being undertaken and at any other locations determined as a result of risk assessments or required as part of a standard safe work method.

The fire extinguishers should be maintained and regularly inspected, and staff should be trained in the use of manual firefighting equipment.

7.5 Hydrants and Hose Reels

All hydrants and hose reels required by the NCC for the completed building must be fully operational and any required booster connections must be installed for the building under construction as soon as reasonably practicable.

The NCC deemed-to-satisfy provisions[14] require the following:

"After the building has exceeded an effective height of 12 metres.

(iii) The required fire hydrants and fire hose reels must be operational in at least every storey that is covered by the roof or floor structure above except the two uppermost storeys and

(iv) any required booster connections must be installed."

8 Temporary Buildings and Accommodation

Locate temporary offices and sheds and other storage facilities having combustible construction or contents as far as practicable from the building under construction or other occupied buildings.

Use risk assessment to determine fire precautions within temporary buildings and accommodation including temporary fixed fire protection systems, portable firefighting equipment and alarm systems.

Internal linings should comply with the Deemed-to-Satisfy provisions of the NCC based on the most appropriate NCC building classification unless a risk assessment has been undertaken.

9 Performance Solutions

The National Construction Code offers two pathways to compliance:

- satisfy the Deemed-to-Satisfy provisions; or
- demonstrate that an Performance Solution meets the performance requirements.

Where the Performance Solution approach is adopted, a fire safety engineer (the designer) will prepare a fire engineering report assessing the design against relevant performance requirements of the NCC. Under some circumstances, the Performance Solution may need to be assessed for its impact on fire safety during construction against performance requirement E1.5 and, if appropriate, additional precautions may be nominated in the fire safety engineering report. Items that may need consideration include:

- fire properties of materials used during construction;
- structural protection during construction;
- materials and methods to reduce the need for hot work on site;
- design details that prevent or restrict the passage of fire and smoke through the building;
- design of evacuation routes;
- fire brigade access to the site; and
- fire protection firefighting and alarm systems.

10 Construction Zones within Occupied Buildings

Renovation and maintenance activities are often undertaken while buildings are occupied, presenting a number of challenges to WHS responsibilities. The employer(s) of people working in the building and the building owner, in addition to the principal contractor, need to be actively involved in managing fire safety while the construction work is undertaken.

Common issues to be addressed include:

- isolation of existing fire protection systems in occupied areas in addition to the construction zone;
- verification of alarm system performance after adjustments/reprogramming;
- fire and smoke separation of the construction zone from the occupied areas;
- security to prevent unauthorised access to work areas;
- blocking of evacuation paths from occupied parts of the building;
- disturbance of service penetrations through existing fire separations; and
- modification of the performance of smoke management systems and firefighting equipment.

The planning phase is critical to ensure that acceptable safety levels are maintained during the construction works. The principal contractor should take the lead in preparing a site Fire Safety Plan but senior representatives of the employers of people working in the premises and the building owner should be involved in developing a plan that addresses all stages of the construction project.

A joint fire safety committee should be established with the responsibility for the establishment, validation and implementation of the emergency plan and procedures for the facility, including construction zones, for the duration of the construction project.

A combined emergency control committee should be established with the responsibilities of individuals clearly defined. It should ensure that issues such as those listed above are adequately addressed in addition to those of a typical construction site or workplace.

Further advice in relation to fire precautions whilst building works are being undertaken within occupied buildings can be obtained from Engineers Australia Society For Fire Safety Practice Note for Fire & Life Safety in Existing Buildings During Construction[15].

11 Bushfire Safety

Where a construction site is in an area where there is a risk of bushfire, additional controls will need to be put in place including:

- restrict hot work activities on days of high bushfire risk;
- where reasonably practicable, plan construction phases so that the external façade of the building is in place before the bushfire season begins;
- where reasonably practicable, protect openings in the building under construction if the contents are susceptible to ignition by embers;
- clear excess vegetation around the building as permitted by the relevant council or shire;
- minimise storage of combustible materials on the site; and
- if combustibles need to be stored on site, provide non-combustible or fire retardant treated covers.

12 Sources of Additional Information

In addition to the documents referenced in the body of this guide the following documents provide useful information relating to managing the risk of fires during construction however it should be noted that whilst the same general principles apply these documents relate to regulatory systems, codes and building practices that may differ from those in Australia.

- NFPA 241 Standard for Safeguarding Construction, Alteration and Demolition Operations[16].
- Fire safety in construction - Guidance for clients, designers and those managing and carrying out construction work involving significant fire risks[17].

13 References

1. National Construction Code Series 2019 Volume One, Building Code of Australia Class 2 to Class 9 Buildings: Australia Building Codes Board, Canberra ACT.
2. Model Work Health and Safety Bill: Safe Work Australia; Commonwealth of Australia 2016.
3. Performance requirement EP1.5 Fire precautions during construction, National Construction Code Series 2019 Volume One, Building Code of Australia Class 2 to Class 9 Buildings: Australia Building Codes Board, Canberra ACT.
4. Clause E1.9 Fire precautions during construction, National Construction Code Series 2019 Volume One, Building Code of Australia Class 2 to Class 9 Buildings: Australia Building Codes Board, Canberra ACT.
5. Specification C1.10 National Construction Code, Volume one, Building Code of Australia Class 2 to Class 9 Buildings 2019: Australia Building Codes Board, Canberra ACT.
6. Clause E1.9(b) Fire precautions during construction, National Construction Code Series 2019 Volume One.
7. Model Work Health and Safety Regulations Safe Work Australia 2019.
8. *AS 2118 – AS 2118 Automatic fire sprinkler systems;* Standards Australia. The following editions are referenced in the 2019 edition of the NCC. Part 1 2017 General requirements 2017, Part 4 Residential 2012, or Part 6 Combined sprinkler and hydrant 2012.
9. *AS 2419 Fire Hydrant Installations Part 1 System Design Installation and Commissioning*; Standards Australia 2005.
10. *AS 2441 Installation of Fire Hose Reels*; Standards Australia 2005.
11. *AS 3745-2010 Planning for Emergencies in Facilities*. Standards Australia 2010.
12. Clause E1.9(a) Fire Precautions During Construction, National Construction Code Series 2019 Volume One
13. *AS 2444 Portable fire extinguishers and fire blankets – Selection and location*; Standards Australia 2001.
14. Clause E1.9(b) Fire Precautions During Construction, National Construction Code Series 2019 Volume One.
15. Engineers Australia Society of Fire Safety, *Practice Note for Fire & Life Safety in Existing Buildings During Construction*. 2012, Engineers Australia: NSW.
16. NFPA 241 Standard for Safeguarding Construction, Alteration and Demolition Operations. National Fire Protection Association,Quincy USA 2019.
17. Fire safety in construction - Guidance for clients, designers and those managing and carrying out construction work involving significant fire risks, HSE, Office of Public Sector Information, UK. 2010.