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Moisture Management of Mass Timber Construction

Technical Design Guide issued by Forest and Wood Products Australia

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1 Introduction

It is essential to protect buildings from prolonged excessive exposure to moisture during construction. Timber and wood products are hygroscopic materials, meaning they can absorb (take in) or adsorb (let out) water from their surroundings. Wood, irrespective of age, always balances its moisture content with its surroundings.

Prolonged excessive exposure to moisture may affect the timber's strength and dimension stability, i.e. shrinkage or expansion, or provide an environment for mould growth, staining and eventually deterioration. Figure 1 shows mould growth on a mass timber column.

Figure 1: Mould growth on mass timber column (Image credit: TDA)

This guide discusses the effects of timber exposure to excessive moisture, provides strategies to minimise moisture ingress during construction, and recommends remedial actions if necessary. Construction on building sites inevitably needs some level of remediation that may require budgetary and program allowance by the contractor. The guide focuses on mass timber buildings, generally associated with non-residential construction. A separate WoodSolutions Technical Design Guide provides advice on moisture management for timber-framed buildings.

2 Wood and Moisture

Before being manufactured into timber, the wood in trees withstands decades of exposure to weather without significant deterioration or change. It is when we place it in service that we experience difficulties. The living tree requires large quantities of water to enable soil nutrients to be conveyed to the leaves for photosynthesis. Trees contain 40% to 200% water compared to their dry mass[1]. This high moisture content in the wood protects the trees from fungal attack.

Moisture content (MC) is a measure of how much water is contained in a piece of wood relative to the wood itself. Moisture content is expressed as a percentage and calculated by dividing the weight of water in the wood by the weight of that wood with no water, i.e. oven-dried.

When freshly harvested, the wood is saturated with water, mainly contained in the space in the wood cells and some combined within the cell's walls (see Figure 2a). However, wood is a hygroscopic material, which means it can release or absorb moisture to reach a moisture content at equilibrium with its surrounding environment. The freshly harvested wood wants to dry out, and the water contained within the cell space is lost first until there is no more. This is termed the 'fibre saturation point'. Any further moisture within the wood is combined with the cell walls. Fibre Saturation Point varies for each timber species, generally around 26% to 28% being the average. Radiant pine is a little higher at 29%[1] (see Figure 2b).

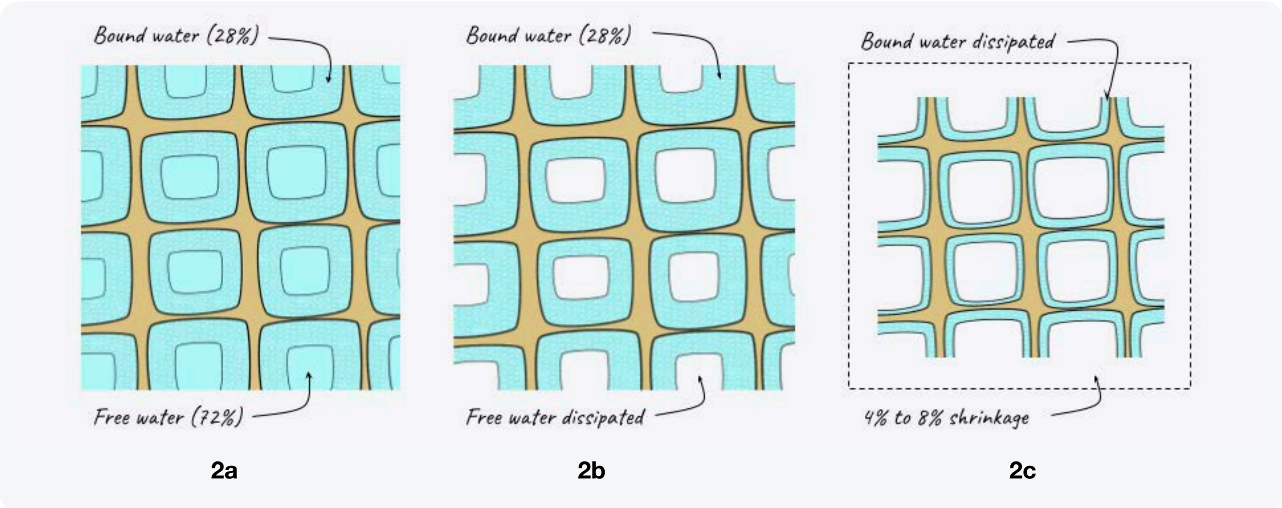

Figure 2: Water located in the timber structure at various moisture contents. (Image: TDA)

Wood continues to dry until it is balanced with the surrounding atmosphere's relative humidity, termed equilibrium moisture content. The water is in the form of water molecules that come from the wood's cell walls as it dries. This removal of the water molecules causes dimensional change to the timber, generally referred to as shrinkage (see Figure 2c). Before reaching the fibre saturation point, there is no dimensional change to the wood.

2.1 Where Timber Obtains Moisture

Timber can obtain moisture directly from liquids it is in touch with or water vapour in the atmosphere. Often, strategies for timber protection are to minimise liquid water. These strategies include surface coatings, sloping elements, drainage and coverings, discussed in detail later. They are aimed at shedding the water away from the timber surface.

Atmospheric moisture is not prevented by these strategies, including coating. Timber adjusts its moisture content as the atmospheric moisture changes, termed relative humidity.

2.2 Relative Humidity and Wood

Relative humidity (RH) is the amount of moisture in the air as a percentage of the amount the air can hold. Warmer air can hold more moisture than cooler air, meaning that for a given amount of atmospheric moisture, the relative humidity is lower if the air is warmer than it would be if the air is cooler. Most people find an environment with a relative humidity between 40% and 60% to be the most comfortable. Humans tend to condition the environment until this ideal relative humidity is achieved.

The moisture content of wood not in direct weather exposure is directly related to the relative humidity of its surroundings. The moisture in the wood attempts to balance with the moisture in the air. Relative humidity between 40 and 60% and a temperature of 20°C results in wood likely to have a moisture content of 8-12% (see Figure 3). The ideal moisture content for timber used in service within a building is the average for the relative humidity range the wood finds itself. For unconditioned building environments, this is around 11-12%. For conditioned environments, this moisture content is usually a couple of percentage points lower, i.e. 9-11%.

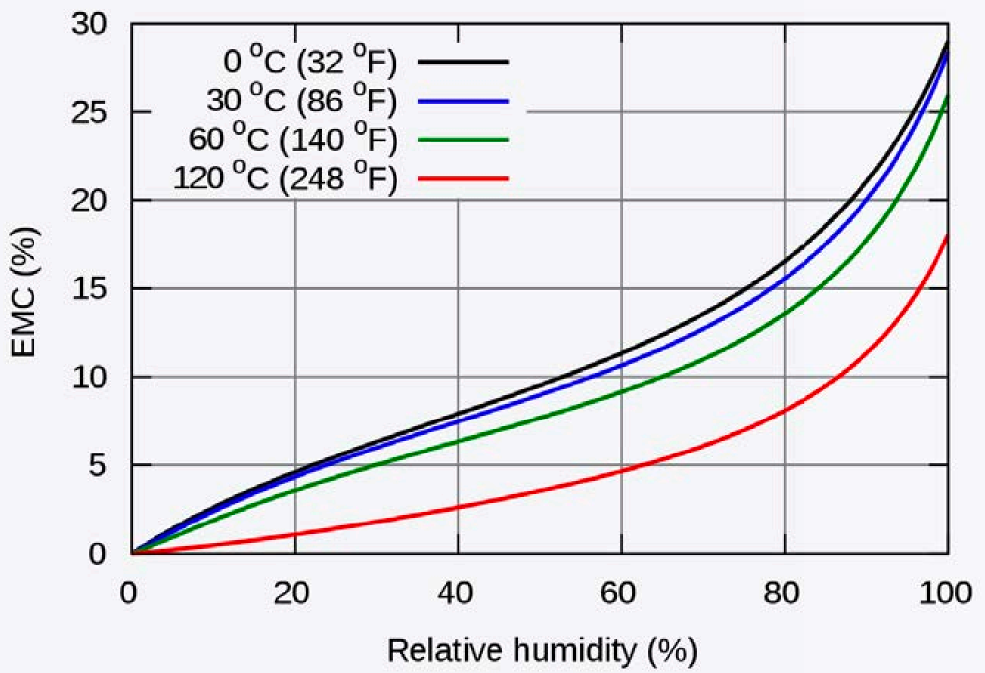

Figure 3: Moisture content of wood at different relative humidities (at 20°C). (Image: Wikipedia)

2.3 The Moisture Content of Timber at the Time of Sale

At the time of sale, moisture content for timber supplied for feature products, such as floors, must meet the following requirements:

- Hardwoods: 9–14% moisture content with an average of 11%[2]
- Softwoods: 9–14% moisture content with an average of 11%[3]
- White cypress: 10–15% moisture content with an average of 12%[4]

On the other hand, if structural timber is described as seasoned, for example, MGP or kiln-dried timber, it must have a moisture content of 15% or lower[5] at the time of grading.

Most timber sold, unless described as unseasoned or green timber, will have a targeted 11-12% moisture content, which is within the range of the moisture content from the ideal relative humidity.

2.3.1 Measuring Moisture Content of Timber

Moisture content is generally measured by a meter, where two probes are pressed into the timber surface and the electrical properties of the wood provide an estimate of the moisture content. Where a precise moisture content of the wood is required, the oven-dry method is used. This method is where the weight of the sample is compared to its weight after the sample is dried out in an oven.

Moisture meters

There are two types of meters: resistance and capacitance. The resistance meter measures timber's electrical resistance when a current flow is passed between two pins (see Figure 4). The resistance to passing a current reduces as the moisture in timber increases. The reading is influenced by the temperature and timber species; therefore, correction factors are applied to the reading. Modern meters can do this automatically.

Moisture meters with short, uninsulated probes can only estimate the surface moisture content, which may differ substantially from the average moisture content of the piece. Such meters should only be used to check surface moisture content, for example, before painting or installing membranes. Resistance moisture meters with insulated hammer electrodes should be used where more accurate readings are required. They work on the principle of measuring the resistance between two insulated probes inserted into the timber.

Figure 4: Resistance moisture meter. (Image: TDA)

On the other hand, a capacitance meter measures an electrical property called the 'dielectric constant'. The meter produces an electric field within the timber on which the meter is positioned. The moisture content and the density of the timber affect this electrical property; consequently, the reading requires correction for density. Furthermore, the measurements can also be adversely affected by electrically conductive materials near the piece of wood, such as a steel beam underneath it.

At best, moisture meters estimate the moisture content at the point where they are applied. The moisture content may vary to some extent down its length and from the outer surfaces (case) to the centre (core). Moisture readings should be taken at least 300 mm from the end of the piece of timber and at least one-third in from the edge. They are also susceptible to some preservative-treated timber or salt environments, and corrections for these conditions are required.

For further information, see Technical Data Sheet 27 Measuring the Moisture Content of Timber, Timber Queensland[6].

2.4 Shrinkage and Expansion

When wood dries below its fibre saturation point, water in wood is bound within the cell walls of the wood structure. Removing this water makes minor changes to the thickness of the cell walls. The accumulation of this reduction over thousands of cells causes reductions in the thickness of the timber. This reduction in the wood cell walls causes little change in the longitudinal dimension, i.e. along the grain. However, across the grain, this is not the case. Wood movement across the grain depends on whether it is radial or tangential to the growth rings. Radial shrinkage is perpendicular to the growth rings, i.e. its movement is towards the tree's centre.

Tangential shrinkage is in the direction parallel to the growth rings. Its movement rate is usually twice that of the radial direction because radial shrinkage is partially restrained by medullary rays, i.e. fibres that run perpendicular to the growth rings.

The amount of movement in wood is also dependent upon the wood species, the thickness of the timber, the part of the log from which the timber was cut, the initial moisture content, the rate of change of moisture and the environment in which the timber is placed.

Movement tends to be more pronounced for hardwoods than for softwoods. However, regardless of the species, appropriate allowances for movement must be made in detailing all timber used in service. Shrinkage effects are more significant for unseasoned timber allowed to dry in service. In this case, careful design is required to limit the effects of shrinkage, particularly around connections where splitting may occur.

Designers rarely know which cross-sectional dimension is radial and which is tangential, so shrinkage is often estimated for each cross-sectional dimension using the data for the tangential direction.

The Residential Timber Framing Standard AS 1684[7] provides Unit Tangential movement (%) for commonly available timber species. The Unit tangential movement is the dimensional percentage change for each 1% moisture content change between 3% moisture content and the fibre saturation point for the particular species. Table 1 provides the Unit Tangential movement per cent for common structural timbers.

Table 1: Unit Tangential Movement per cent for common structural timbers.

Timber Species	Unit Tangential Movement per cent
Blackbutt	0.37
Spotted gum	0.38
Radiata pine	0.27
Victorian Ash or Tasmanian Oak	0.36
Cypress pine	0.26

Note: The Unit Tangential Movement is based on AS 1684[7]

Example calculation

Dimensional change of a 90 x 45 radiata pine stud thickness from expected moisture content change due to exposure during construction, i.e. 4%.

Unit Tangential Movement per cent is 0.27 each 1% moisture content

∴ 45 x 0.27/100 x 4 = 0.48 mm

Care is required not to apply the calculation method directly to thick mass timber unless the average moisture content of the element is known. Thick timber has a moisture gradient through it, and the surface moisture content that is often measured would not represent the average moisture content of the element.

3 The consequence of Excessive Wetting or Drying

Excessive wetting of timber can cause several issues:

- Staining
  - water staining
  - iron staining
  - tannin staining
- Mould growth
- Algae growth
- Decay
- Fasteners corrosion
- Dimensional change – checking and cracking.

Staining, mould and algae affect the surface appearance of the timber, while decay and fastener corrosion may affect the timber or element's strength. Dimensional change may cause appearance issues from cracks and checks to structural issues from differential movement or the splitting of the timber. The following discusses each in detail as well as provides remediation.

3.1 Staining

3.1.1 Water staining

Exposure to liquid water on the timber surface can cause leaching of tannins, resins or extractives. The mobilisation of the tannins, resins, or extractives causes discolouration that may affect the timber surface's appearance (see Figure 5).

Figure 5: Water staining on the underside of a CLT panel. (Image: TDA)

Preventative Measure

Management of the moisture on construction sites may reduce water staining (see Section 4).

Remediation

For timber elements that have a smooth surface, sanding the surface may remove some of the water stains. However, prolonged exposure to water may mean the watermark is more than just on the surface and may have penetrated the timber.

For rough surfaces or deeply penetrated water stains, using a bleaching agent that contains oxalic acid may remove mild to moderate water stains. However, it can also lighten the colour of the wood. The application of wood stain to match the surrounding wood may be required. Both methods may require the top coat to be reapplied when a top coating is present.

Before any chemical treatment or coating is applied, acceptance from the building stakeholders or owner should be obtained.

3.1.2 Iron staining

Iron particles from cutting wheels, fasteners, and strapping react with phenolic chemicals in wood under the presence of moisture, causing dark staining (see Figure 6). The dark stain is an appearance issue that does not affect the timber strength.

Preventative Measure

Design the structure so that tannin bleed does not affect the support structure or the underneath surfaces. Where this can't be avoided, use timber species that don't bleed tannins. Alternatively, seal the underlying structure and surfaces so that any tannin bleed can be easily washed off. As tannin is water-soluble, the quantity of tannin from the timber will reduce over time.

Figure 6: Iron staining on wood from metal nails. (Image: TDA)

For information on the choice of the material the fastener is to be made from, refer to WoodSolution Guide #52, Timber Connectors[8].

Remediation

For timber elements that have a smooth surface, sanding the surface may remove some of the iron stains. However, prolonged exposure to water may mean the iron stain is more than just on the surface and may have penetrated the timber.

Using a bleaching agent that contains oxalic acid may remove mild to moderate iron stains for rough surfaces or deeply penetrated iron stains. However, it can also lighten the colour of the wood. The application of wood stain to match the surrounding wood may be required. Both methods may require the top coat to be reapplied when a top coating is present.

Before any chemical treatment or coating is applied, acceptance from the building stakeholders or owner should be obtained.

3.1.3 Tannin staining

Tannins are stored in the cell structure of hardwood timber. They are water-soluble and can wash out through the end grain of the timber. The tannins may stain the surrounding support structure or underlying surfaces (see Figure 7).

Figure 7: Tannin staining to support structure. (Image: Place holder)

Preventative Measure

Design the structure so that tannin bleed does not affect the support structure or the underneath surfaces. Where this can't be avoided, use timber species that don't bleed tannins. Alternatively, seal the underlying structure and surfaces so that any tannin bleed can be easily washed off. As tannin is water-soluble, the quantity of tannin from the timber will reduce over time.

Where tannin bleeding timber species can't be avoided, remove the surface tannins by pre-weathering or using a proprietary tannin remover. Allow to dry, and then coat the timber all around with a timber finish on all surfaces. The timber finish may reduce the quantity of water available to become soluble with the tannins in the first instance.

Remediation

Tannins being water-soluble means they can generally be cleaned with soapy water if attended to shortly after leaching. However, an oxalic acid-base timber cleaning product may be required if left for a more extended period.

3.1.4 Fasteners corrosion

Fasteners are susceptible to corrosion in the presence of moisture. Some copper-based preservative treatments can speed up the corrosion of the fasteners (see Figure 6). Also, in the presence of moisture, there is a potential to degrade the wood around the fastener, often seen by the fastener staining the surrounding wood. The fastener is typically critical for strength, and stain is only a minor issue.

Preventative Measure

Use a durable fastener for the intended environment. Also, avoid galvanic corrosion for dissimilar metals. For further information, refer to *WoodSolutions Guides #52 Timber Connectors*[8] and *WoodSolutions Guides #5 – Timber Design Life* for design advice and service life of fasteners[9].

Remediation

Where fasteners have extensively corroded, there is no remedial measure other than replacement.

3.2 Mould

Mould growth can be sooty black and unsightly, spreading rapidly in favourable circumstances, especially warm, humid weather (see Figure 8). Mould is a fungus and not a plant, and it produces spores. It feeds off the starches and sugars on the surface of the timber. Mould growth is superficial and will not influence the structural or durability of timber elements. Mould spores are always present outdoors and in buildings and are distributed by wind, insects, floods, animals and human activity. All buildings have a background concentration of settled spores.

Figure 8: Mould on timber beam. (Image: TDA)

Mould will colonise on a wide variety of construction materials and building contents. Exposed soil within a building (e.g. a dirt subfloor space) is another area of potential mould growth. While some inorganic materials, such as fibreglass insulation or plaster and other masonry products, may not support mould growth, they may contain dirt or have surface coatings that can support growth.

Mould requires three key components to survive: a nutrient source or growth medium, a source of moisture, and favourable environmental conditions (e.g. temperature). Many construction materials contain enough organic material to cultivate mould when wet and within suitable temperatures. Mould is frequently found on the wet paper used in plasterboard wallboard and other materials with a high cellulose content, wood.

Most moulds reproduce by forming large numbers of spores. Active mould growth indicates continuing moisture problems, and it is recommended to be investigated. Mould growth can occur on treated and untreated timber and on kiln-dried timber.

3.2.1 Mould growth on timber

Mould requires water, food and oxygen to grow. It also requires an environment with a temperature it can survive. Most moulds cannot grow below 4°C; the temperature at which food is typically refrigerated. Mould grows best between 25° and 30°C, especially if the air is humid, e.g. wet summer conditions. While mould cannot spread without these conditions, its spores may survive in a dormant state until conditions are suitable.

Moulds are obligate aerobes, meaning they need oxygen to survive. Mould grows even at very low concentrations of oxygen, making it challenging to fight mould growth by limiting oxygen.

Wood has starches and sugars on the surface that can support mould growth. For mould growth to occur on timber, the moisture content must be above 19% for a week or more. To survive, the moisture content of the timber must be maintained between 20% and 28%[10].

Their presence is related to temperature, humidity, wetting and the presence of atmospheric mould spores. Therefore, it is more likely to see mould during the hot and wetter months of the year or when the relative humidity is greater than 80% (see Figure 9).

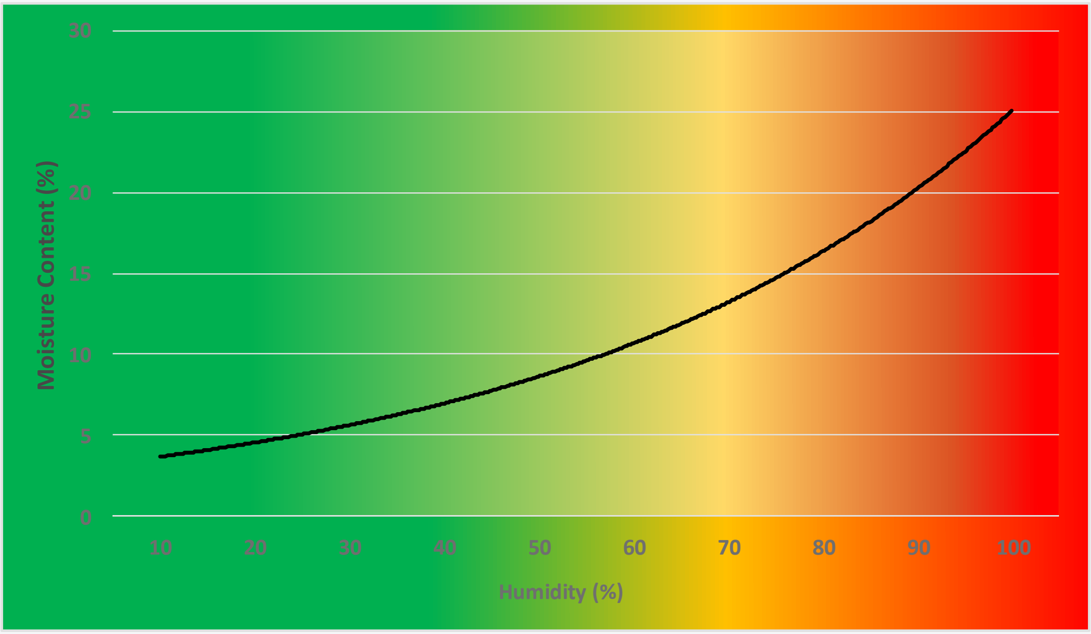

Figure 9: Timber moisture content, relative humidity and the risk of mould. (Image: TDA)

Moulds are generally black; however, some moulds are green and should not be confused with algae, as discussed later. Moulds can occur on treated timber.

3.2.2 Effect of moulds on timber

Moulds on timber occur on the surface, and the timber is not weakened by their presence even when left for lengthy periods. Mould can also be a health issue causing a runny or blocked nose, irritation of the eyes and skin and sometimes wheezing. For people with asthma, inhaling mould spores may cause an asthma attack. Very rarely, people may develop a severe mould infection, usually in the lungs.

In wet situations, e.g. floors, moulds can be slippery, which becomes a safety issue.

With appropriate treatment, they don't become decay hazards.

Preventative Measure

Although it is impossible to eliminate mould spores and nutrients from the construction process, it is possible to control the other element that promotes mould growth, moisture. Limiting the free water on the construction site is the best strategy to minimise mould growth. Refer to Section 4 for strategies to reduce moisture on construction sites.

Remediation

While moulds do not affect the performance of the timber, the application of biocide products can kill the mould and restore the appearance of the timber. Some of these products take time to kill the mould; black mould can decompose for up to 4 to 6 months, while green growth takes up to 2 weeks. Alternatively, a timber restorer that contains oxalic acid or similar can be used.

Bleach is not recommended as bleach can't kill mould on porous surfaces, such as those made of wood. Even after applying bleach and wiping away mould from these surfaces, the mould may continue to grow beneath the surface and return to the area cleaned in a short time because mould spreads its roots deep into porous surfaces.

High-pressure water cleaners are not recommended for exposed or decorative timber. The high-pressure cleaner can cause the wood fibres on the surface to be dislodged, destroying the milled surface appearance. Also, the high-pressure cleaner may increase the moisture content of the timber, promoting mould growth to return.

3.3 Algae

Algae are nucleus-bearing organisms that lack a plant's true roots, stems and leaves. Algae is different from mould, a fungus that eats nutrients to survive, while algae are more plant-like, containing chlorophyll (see Figure 10).

Algae are associated with surface water compared to mould, which is associated with high moisture content timber. Algae may grow on all surfaces, as it does not feed off the substrate it is on. Its presence does not often affect timber substrate, more of a safety issue due to slip hazards.

Figure 10: Algae on a timber fence. (Image: TDA)

Prevention Measure

Limiting the free water on the construction site is the best strategy to minimise algae growth. Refer to Section 4 for strategies to reduce water on construction sites.

Remediation

The application of proprietary biocide products can restore the appearance of the timber.

3.4 Decay

Wood provides a suitable substrate for wood-decaying fungus to grow, and the cellulose, lignin and other components of the cell walls and wood tissues provide suitable food. Some wood species are more naturally durable because they contain toxic substances to fungi. However, all sapwood in any timber species is susceptible to fungi as starches and sugar are present.

The moisture content essentially controls the development of fungi in wood. All wood-decaying fungi require moderate amounts of water for growth. Timber moisture content must be greater than the fibre saturation point of timber at approximately 28% (but can vary depending on the species) for wood-decaying fungi to develop. This condition must exist for more than a week for these fungi to develop and survive.

Fungi require a food supply and oxygen to survive, which is derived from the wood cells. The optimum temperature for fungal activity is between 24°C and 30°C. Fungal activity is dormant at 0°C and diminishes beyond 30°C.

If there is insufficient moisture after fungal growth has started, the fungi do not necessarily die but become dormant. Active growth can start again, sometimes years later, when sufficient moisture returns.

Fungi-attacked wood left for an extended period may affect the timber strength.

3.4.1 Brown, white and soft rot

There are three common types of fungi: brown, white and soft rots. Brown rot fungi attack the wood's cellulose, leaving the lignin, which is dark in colour. On the other hand, white-rot fungi concentrate their attack on the lignin, leaving the cellulose, which is light in colour. Soft rot fungi, like brown rot fungi, tend to attack cellulose. Wood affected by soft rot may change to a slightly darker colour but often remains very similar in colour to the original wood colour.

Preventative Measures

Moisture control is the best way to limit fungal growth for timber used within a structure. Keeping the timber below 20% moisture content may prevent fungal growth. The presence of mould usually pre-empts conditions for fungal growth. Mould is likely to occur before decay fungi and is a sign that decay fungi growth could occur.

Where timber is expected to be in high moisture content environments, such as exterior environments, it is possible to eliminate the food supply by treating the timber with preservative treatments. Alternatively, use timber with high extractive contents or natural durability. The sapwood of all timber is susceptible to fungi attack. Refer to *WoodSolutions Technical Design Guide #5 Timber Service Life*[9] for more information.

Remediation

Once the wood has decayed, there is no way to return it to its original state. In this situation, it is best to return the wood to conditions that are not conducive to decay to prevent further rot. Some brush-on preservatives such as copper naphthenate or boron may be used to prevent further decay.

Where the timber element has lost its strength carry capacity, it is recommended that the element is replaced. An assessment by a structural engineer is recommended for advice on any remedial action needed.

3.4.2 Blue stain in wood

Blue staining (see Figure 11) is another fungus that grows in sapwood and uses sapwood for food. It is not a stage of decay, although the conditions that favour blue staining also very often lead to infection with decay-producing fungi. Excepting toughness, blue staining has little effect on the strength of wood, and consequently, non-appearance grade timber elements may contain some blue stain components within them.

Figure 11: Blue stain laminations within CLT. (Image: TDA)

Blue staining is mentioned as it often has already stained the timber at the time of manufacture. Blue staining often appears during the harvesting and processing of wood into timber, particularly during the humid months of the year. As it has little effect on strength, often blue-stained timber is incorporated into non-visual products. The blue-stain fungi cannot grow in wood with a moisture content of less than 20% nor in wood where the cell cavities are full of water. Hence, staining can be prevented by drying freshly exposed surfaces to a moisture content below 20%.

3.5 Cracking and Surface Checking

Checks, cracks and splits in timbers are often misunderstood when assessing the condition of a structure. A check is the separation of wood fibres across the annual rings, and a crack is a separation of wood fibres across the annual rings but through the entire piece of wood. Refer to Figure 12 (a) for a crack, Figure 12 (b) for checking and Figure 12 (c) for an internal check.

(a) Crack (b) Surface checking (c) Internal check

Figure 12: Check and cracks in timber. (Image: TDA)

During the drying-out process, any change in moisture content below the fibre saturation point results in a dimensional change to the timber. Moisture moves 10% to 25% faster along the grain than across it[1] because the moisture movement in the radial direction is two to four times faster than in the tangential direction. It is also likely to dry out quicker at the ends than the middle of the piece of timber.

Stresses develop in wood due to differential shrinkage, leading to checking, cracking and even cupping. Wood shrinks or expands approximately twice as much in the tangential direction of the annual rings compared to the radial direction. During the initial drying, the surface dries quicker than the interior, which causes differential stresses to develop within the timber element.

The weakest strength property in wood is tension perpendicular to the grain; drying stresses can result in a check or cracks that form in a radial direction across the annual rings. It is important to remember that as the wood dries, it strengthens. Also, visual stress grading rules allow checks up to 2.0 mm wide and 450-600 mm long, depending on structural grade. Therefore. the development of seasoning characteristics such as checking is normal and expected.

Although checking and cracking in timber elements are naturally occurring and expected, cracks sometimes occur for other reasons, such as timber restrained by metal connectors. Where this occurs, an assessment by a knowledgeable structural engineer is required.

Preventative Measures

Managing moisture on the construction site may reduce the amount of checking and cracking. Furthermore, the appropriate drying and acclimatising of the structure may reduce checks and cracking (see Section 4.6).

Remediation

Where excessive checking or cracking occurs, wood fillers or putty can be used to fill in any checks or cracks. Where significant spitting occurs, an assessment of its structural capacity is required, and the assessor may provide the appropriate remedial action if any is required.

3.6 Sunburn or Suntanning

In general, all wood species change colour over time as a result of exposure to natural light and oxidation of the wood fibres (see Figure 13). Over the long term, the colour differences will even out and, in most instances, may disappear altogether. Prolonged exposure to the sunlight leads to UV-induced discolouration and darkening of the timber, noticeable when a temporary structure is used covering part of the element, i.e. props or wrapping. If a portion of the panel has been left uncovered in the sun for a period of time or there is a tear in the wrap or improperly covering the panel at the construction site. Elements on the exterior face of the building may be affected more than interior elements and require greater attention.

Figure 13: Sunburn/tan marks on mass timber beam. (Image: TDA)

Remediation

Sanding of the affected areas may remove the suntanned marks. If it is deemed necessary, the colour difference can be corrected by using a stain.

4 Construction Moisture Management

Of the various elements discussed above, one critical underlying component is consistent: excessive moisture during the construction stage (see Figure 14). Strategies to manage excessive moisture may reduce the likelihood of these degradation agents occurring on mass timber elements.

Figure 14: Excessive water on a mass timber construction site. (Image: TDA)

Figure 15 shows the moisture content of CLT during the installation, construction and occupation of a six-storey building in Sydney over 18 months. The moisture content is measured using a Point Moisture Measurement, 17 mm from the CLT surface.

Figure 15: Moisture content of underside of the CLT floor and CLT wall during construction (Image: TDA)

The CLT wall graph indicated that the moisture content during installation was high, well into the zone where mould could grow. If the CLT wall element were left exposed to the weather, it would have likely grown mould. On the other hand, the CLT floor did not have this initial high moisture content, as it was measured below the CLT floor in a protected location. However, both showed fluctuations in moisture content varying from 21% to 10% during the construction phase.

An analysis of the moisture content of a timber stud against the recorded rainfall on the same site indicated a rise in moisture content after each significant rainfall event (see Figure 16). Furthermore, the moisture content was high during the time it was exposed directly to the weather.

Figure 16: Rainfall data overlaid onto the moisture content of a wall stud (image: TDA)

A timber structure is highly likely to be exposed to moisture during its construction phase, both from direct weather and atmospheric moisture. Without a careful, thought-out construction sequence, any additional moisture may create conditions conducive to supporting mould growth or fungal attack. The fundamental strategy is to stay dry enough to prevent mould spores from becoming active, even if the structure is exposed to water during the installation.

4.2 Mass Timber Manufacturer

The successful management of the excessive moisture begins with the manufacturer of the mass timber product. If the mass timber element does not remain dry during the manufacturing stage, follow-on activities are unlikely to be effective.

The mass timber manufacturer should:

1. Provide transport companies instructions on handling and any trans-shipping storage.
2. Provide instructions on on-site storage and handling. Refer later for recommended site storage practices.
3. Apply an end sealer or tape in the factory at all end grain locations, including cuts and service openings. This could occur on the construction site or at the transhipping location.
4. Cover all elements individually or bundle them together before shipping with secured light-coloured opaque wrap. Secure using straps or tape. A UV-resistant wrap is recommended when elements are used as decorative surfaces. Note: dark colour wraps attract heat, creating an environment conducive to high humidity (see Figure 17).
5. Before leaving the factory, take sample moisture contents of the accessible elements. Where wrapping is damaged, repair the wrapping. Record all results and retain them for the project records.

Figure 17: Mass timber elements wrapped for transport. (Image: Xlam Australia)

4.3 Shipping

Mass timber elements are likely to travel some distance from their manufacturer to the construction site. Mass timber might come from many locations, including Australia and overseas, and are likely to have numerous points where they are transhipped from one mode of transport to another. Therefore, all protection to the timber elements must be designed to avoid the likely handling during shipping.

Upon delivery to the construction site, it is recommended to take the moisture content readings of accessible elements. Where wrapping is removed, repair the wrapping. Record the results and pass on to the contractor the moisture content readings.

Where mass timber elements are de-stuffed from containers and stored off-site before delivery, the same precautions as detailed in the site storage should be carried out.

4.4 Construction Site Strategies and Principles

In most cases, timber elements arrive on a construction site near or at their equilibrium moisture content. It is the activities on the construction site that are responsible for introducing moisture back into the timber.

The primary way to prevent moisture from reaching a timber structure is for construction managers to recognise that the installation and the covering of timber elements take precedence over other activities, particularly if the timber element has a decorative finish purpose.

The following principles and strategies should be applied to each building project.

- Minimise site work and time by utilising off-site prefabrication, including precutting and drilling for connections and service openings.
- Schedule timber installation during a relatively dry season, if possible.
- Coordinate material delivery for just-in-time installation to eliminate site storage needs. This includes sequencing the load so that each element that comes off the truck is in the order of assembly.
- Minimise the time of exposure to the elements, particularly for horizontal elements that allow liquid moisture to pool.
- Install the roof and exterior wall structure to complete the enclosure as early as possible to protect the entire structure (see Figure 18).
- Design the structure and each assembly to minimise the potential of trapping moisture by allowing it to drain and dry. The common area is the joints in mass timber floors. In this case, seals should be applied over the joint.

Figure 18: Façade enclosing the building aiding in weather protection. (Image: Tom Roe)

On-site moisture management should be a part of the overall construction plan for the project and be a part of the responsibility of everyone on-site. On-site moisture management requires good communication, cooperation, and coordination among all the parties involved. Major responsibilities include:

- The developer/building owner must set aside funds to cover extra time and measures needed for moisture protection, as well as financial and program allowance for remediation.
- Strategies are needed to protect the timber throughout the entire process (i.e. manufacture, shipping, storage, installation) until the timber is completely protected.

The principle strategy to achieve this can be described as the 3Ds – deflection, drainage and drying.

Deflection

Some form of shielding is applied to limit water from reaching the timber surface. This shielding can come in several forms; wrapping or traps, tapes over joints or end grain, temporary roofs, and enclosure of the buildings. The following contains more detail on each.

Drainage

The timber structure will receive some form of water during its installation. Timber can withstand water for a short period of time. It's when water is present for an extended period that damage occurs. The strategy is to remove the water before it is able to pond. This could take the form of stormwater drains, drain points within the floors, or water diverted away. If ponding water cannot be prevented, then there must be a plan to remove it as soon as practicable.

Drying

It is likely that the moisture content of the structure will be elevated before the structure is enclosed in or a membrane is applied. The moisture content of the timber should be near its equilibrium moisture content or below 16%. Often timber structures are quick to construct, and the natural drying of the structure has not occurred before it needs to be enclosed. Therefore, a strategy is needed to reduce the moisture content by drying or other means. A hold point or inspection point is recommended to check the moisture content of the timber before linings and membranes are installed. Linings and membranes should not be installed until the moisture content of the timber can be maintained at 15% or lower.

The following discusses areas where excessive moisture may come from and strategies to reduce moisture. It also discusses who is responsible for minimising excessive moisture from affecting the timber elements.

4.4.1 Deflection

One of the key strategies is to minimise the timber elements' contact with liquid water. On a construction site, there are many opportunities for this contact. The following discusses this, including strategies to minimise water ingress.

Site storage

As far as possible, plan the delivery of timber elements to minimise the time they are stored on-site. Where timber elements must be stored, they should be stored in a well-ventilated, drained and sheltered location, protected from direct exposure to the weather. The timber elements must be kept at least 150 mm off the ground using bearers (gluts/dunnage). The ground should be free of obstacles, debris and vegetation and well-drained so water does not settle. If the ground is continuously wet, place a waterproof membrane directly on the ground or construct a gravel pad. This recommendation includes concrete slabs where water may pond near or under the stack of timber.

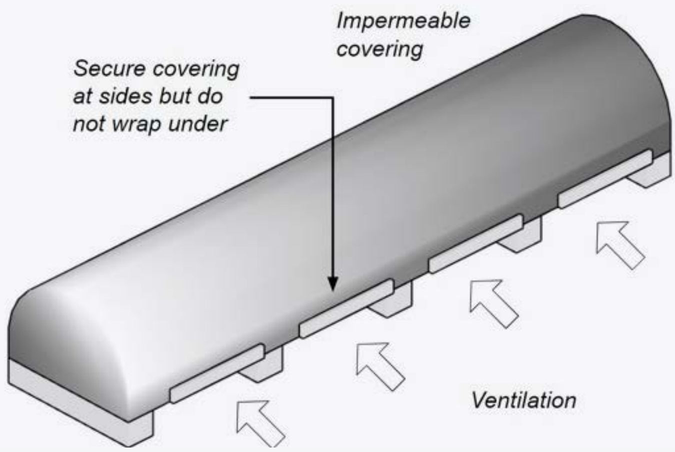

Figure 19: Stored timber elements. (Image credit: TDA)

If sheltered storage is unavailable, cover the timber elements with suitable impermeable covering or tarpaulins. Place the cover to preclude moisture while maintaining good air circulation in and around the timber (see Figure 20). Do not tuck the wrap or tarpaulin under the stack of timber.

Figure 20: Impermeable covering with a respectable spacing of timber elements and airflow. (Image: CWC)

If the wrap or tarpaulin is damaged, make good with tape or remove it and protect the timber with a new impermeable covering or tarpaulin.

Where the free flow of air is not possible, as often occurs when factory-wrapped mass timber elements are transhipped, a vapour-permeable wrap is recommended.

Inspection Point: Monitor the moisture environment of the stored timber. The construction manager should regularly inspect shelters and stored materials to assess moisture accumulation. Check the relative humidity of the environment under the wrap or tarpaulin or take a moisture reading of the stored material. If the relative humidity is greater than 80% or the moisture content rises above 15%, act to improve the ventilation of the storage area.

Factory Wraps

Most wood products come to the site in some form of wrapping. It is best to keep the wrapping in place until they are ready to use or when installed into the building (see Figure 21).

Figure 21: Wrapping left in place to protect the timber element. (Image: XLam Australia)

Where wrapping is removed or becomes damaged, cover using tarpaulins. Do not allow water to pool on the wrap or tarpaulin, especially if the wrap or tarpaulin is in contact with the timber. Ifthe timber element is left with its vapour-impermeable factory wrap affixed to it for an extended period, remove the wrap and replace it with a vapour-permeable wrap.

Site Storage – Fire precautions during construction

Consider fire precautions during construction. The site storage should be away from the main structure and any ignition sources. Where significant volumes of combustible building materials are to be stored on-site, keep them in a secure area at least 10 metres away from 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
- be remote from possible ignition sources such as hot works
- have firefighting equipment close by
- be protected by preventative fire covers (e.g. fire-resistant or non-combustible sheeting).

Deflection of water on the installed Mass Timber Element

Even where the best construction practices are in place, the structure may still be fully exposed to the weather. Alternatively, parts of the structure may be used to provide shelter to the lower storey of the structure, for example, a mass timber floor plate; more later. In this case, any liquid water must be prevented from seeping through the mass timber elements to the lower storey. An effective strategy is to utilise the mass timber floor panel. The area of concern is the joints in the floor panels and any service penetration in the floor or lifting points. In addition to any installed mastic seals used for fire and acoustic reasons, these joints must be covered by a durable water-resisting membrane (see Figure 22).

Another common area is where columns or walls penetrate the floor. Again, the tape can be installed to bridge between the floor and columns (see Figure 23). Where columns are below the top of the floor, special care is required to protect the column's end grain, as this situation often pools water.

Figure 22: Tapes used to cover joints in CLT floors.

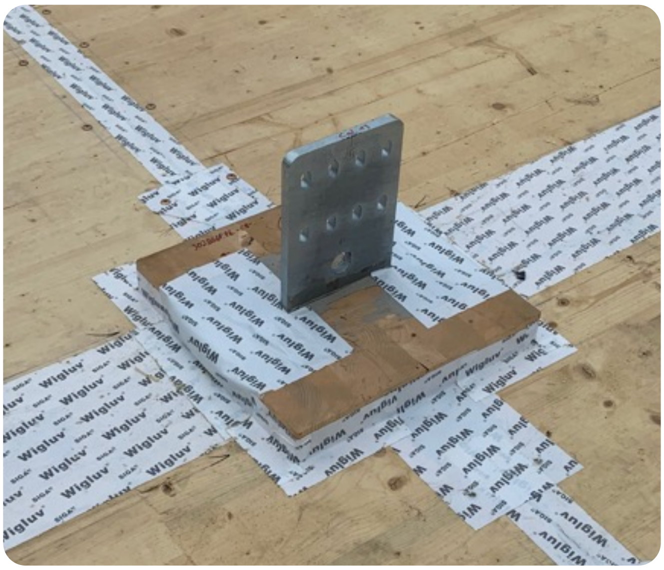

Figure 23: Tape used to bridge the gap between floor plate and column upstand. (Image: TDA)

Tapes need to be regularly inspected, particularly if there are wheeled vehicles operating on the floor.

In addition, seal end grain of any timber elements with tape or sealer (see Figures 24 and 25). Pay particular attention to the wall's base and column elements.

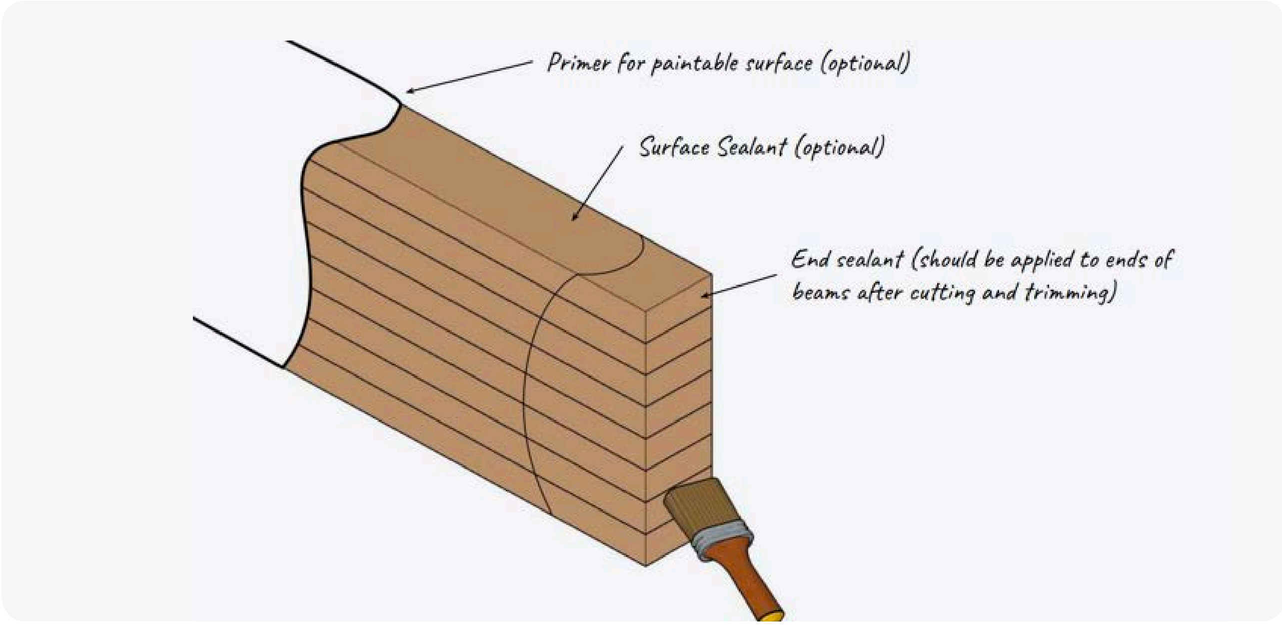

Figure 24: End grain sealer applied to glue-laminated beam.

Figure 25: Tape used to seal joints and end grain. (Image: XLam Australia)

The columns or walls may also need protection, paticularly if they have a decorative function. In this case, retain the factory wrap and fix additional board product to all exposed surfaces of the element (see Figure 26). The additional protection may help reduce on-site construction damage from other trades and protecting the timber from sunburn.

Furthermore, immediately after rain, sweep the liquid water away to temporary drainage points. Setdowns for wet areas can accumulate surface ponding, and it is recommended that temporary drainage points are provided within these areas.

Figure 26: Protection of mass timber columns. (Image: TDA)

4.4.2 Advanced protection where exposed mass timber elements are the finished surface

More advanced site protection is strongly recommended for a building project where the mass timber is expected to be exposed, wet conditions are expected, or the structure may be left for a period of time. The higher initial costs are often offset by reduced time loss, increased construction efficiency and quality, and elimination of re-drying and other remedial needs.

Creating waterproof shells from the walls and floors through construction

Use the existing building components to shelter the inside structure before a full enclosure is possible. This procedure may include the temporary installation of panels or other components installed early.

Install exterior wall cladding or façade

After the major timber elements are installed, fit the exterior wall cladding or façade. Generally, proceed with no more than two storeys of open floors without enclosing the exterior walls. The exterior wall or facade may also provide fall protection (see Figure 19).

Install temporary cladding or tarpaulins where exterior wall openings cannot be closed. Also, seal the floor's joints using membranes or concrete screed if one is to be installed to act as a temporary roof to the lower level of the structure.

Pre-installing self-adhesive membranes on floor or roof

The upper surface of each mass timber panel used for a floor or a roof can have a pre-installed self-adhered membrane in the factory (see Figure 27). Seals should also be applied to the edges and any service openings. This membrane should resist wear and tear and remain water-resistant for the duration of construction. Where it is expected that the membrane may be damaged by construction activity, a thin temporary sheeting over the top of the membrane is recommended. Where this is not possible, plan to regularly inspect and repair the damaged membrane. Furthermore, any membrane used on surfaces where there may be foot traffic during construction (e.g. floors, roofs) should be assessed to ensure that the membrane does not introduce a slipping hazard. Use a vapour-permeable membrane for floor panels where the membrane is in place for a long time.

For the roof, the membrane may serve as part of the permanent roofing membrane; therefore, the type of membrane depends on the configuration of the waterproofing and condensation management.

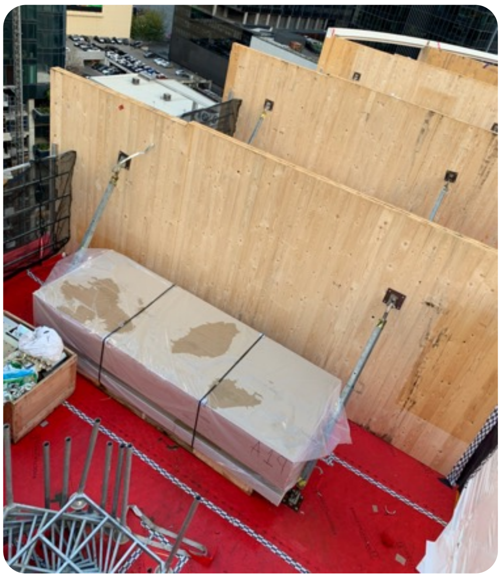

Figure 27: Vapour permeable membrane fixed to CLT floor panels. (Image: TDA)

Seal all joints and interfaces between panels following the panel installation to prevent water from seeping through the gaps and getting trapped within the panel joints. Install the exterior wall cladding or façade and the roof as early as possible to provide a complete enclosure.

Installing a temporary roof

A temporary roof can be installed to shelter the entire or part of the structure. These can be in the form of a fixed tent, utilising scaffolding and tarps. Alternatively, a portable tent, which is raised as each storey is built, is often used in Europe.

Finally, a temporary roof structure that can be lifted at the end of each day or weekend can be used (see Figure 28).

Figure 28: Temporary roof panels awaiting installation. (Image: TDA)

4.5 Drainage

Where water deflection strategies are in place, water may still accumulate and require diversion away from the building. Provide drain holes at any upstands, such as hobs or parapets. Where drainage can't be provided, utilise the holes within the mass timber floor as drainage points. Connect temporary stormwater pipes to drain holes. Where the roof and guttering are installed, connect temporary downpipes to outlets (see Figure 29).

Figure 29: Temporary downpipes (Image: Rotho Blass)

Immediately after a rain event, the liquid water should be swept away to temporary drainage points. Setdowns for wet areas can accumulate surface ponding, and it is recommended to provide temporary drainage points within these areas.

Also, consider that the debris on a construction site may interfere with the drainage. Debris may block drainage holes or accumulate against timber elements and bypass any end grain sealing (see Figure 30).

Figure 30: Debris accumulating against a mass timber wall, leading to moisture bypassing end protection. (Image: XLam Australia)

4.6 Drying and Acclimatising the Building

Drying out the building before linings and covering are installed ensures that any damp timber is not locked into the structure. Strategies to minimise checking/cracking, mainly when the heating, ventilation and air conditioning (HVAC) is commissioned, may reduce checking and cracking in the mass timber. Wet wood (including CLT and joint splines) should be dried before it is closed in.

- Prevent further wetting prior to drying. Remove any liquid water on the surface by vacuuming or mopping.
- Drying occurs naturally when the ambient environment is favourable, i.e. warm air with low relative humidity (e.g. <65%).
- Where the ambient environment is not ideal or the drying needs to be accelerated for a quicker enclosure, use fans, electric space heating (electrical heaters are preferred due to the less risk of construction fires) or dehumidifiers.
- For localised areas, such as joints and connection areas with severe wetting, blowing hot air may provide more efficient drying.
- Non-structural components, such as decorative coverings, plasterboard, insulation, and other coverings, must not be installed on damp timber. A hold point is recommended, where the moisture content is assessed, and approval f rom the contractor is given before sealing in the structure.

4.6.1 Protection against rapid drying

Aesthetical and dimensional issues such as excessive checking, cupping and warping usually result from rapid drying, over-drying, or cyclic wetting and drying. They can occur during construction in a dry climate and in service, particularly when the space is suddenly heated or the HVAC is commissioned.

Dehumidifiers are typically employed to maintain the enclosed space's relative humidity level and slow down timber's drying. A closed space is needed to apply mechanical humidification during construction in a dry climate. Humidity control is essential for a mass timber building in its first few years of service to allow the wood to adjust slowly to the service environment.

The slower the moisture content in the wood equalises with the moisture content in the air, the better. Where heating is applied to buildings, the following should be followed:

- Gradually increase the heat in the building over a 2-3 week period up to average operating temperatures. This procedure may ensure a gradual change in the moisture content of mass timber.
- Do not direct any forced air heating systems onto the mass timber panels.
- Regulate all heating units, remembering that hot air rises and temperatures at the ceiling will be higher than at the floor level.
- Maintain the average relative humidity in the building and monitor it if necessary. Where high humidity is encountered, use a dehumidifier.

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