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Condensation Management in Timber Construction

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2 Scope

This guide is a general best practice for the insulation and construction membranes specification to manage the flow of heat, air, and moisture to avoid surface and interstitial condensation in lightweight and mass timber construction. It is worth noting that these same principles apply to many different construction types, and condensation is an issue that is not exclusive to timber construction.

The guide's intention is to explain the building regulations requirements around condensation management, recommend the level of condensation management for all timber buildings, and provide verified building envelope solutions for lightweight timber-framed and mass timber buildings in four climate zones across Australia, representing the major population centre.

3 What is Condensation

Condensation is the change of water from its gaseous form (water vapour) into liquid water. In buildings, when warm, moist air comes into contact with colder surfaces at or below the Dew point temperature (such as windows), water condenses on those surfaces; refer to Figure 1.

Figure 1: Water condensation on a window (Image credit: TDA)

Everyday activities like cooking, showering, and drying clothes can release moisture into the indoor environment. When this moisture-laden warm air comes into contact with a cold surface and is cooled to the Dew point temperature, condensate or Dew is released and can collect to form water drops; as seen in Figure 2, condensation forms on the pliable building membrane.

Figure 2: Condensation forming on the pliable building membrane (Image credit: Proctor Group Australia)

The difference between indoor and outdoor temperature and absolute humidity is most significant in cool and temperate climates during winter, as the heating is turned up high and the windows are closed, limiting natural ventilation. While buildings in temperate and cool climates are less prone to condensation in the summer months, the opposite could occur in more humid and tropical climates where outdoor moisture-laden air comes into contact with colder surfaces chilled by an air-conditioned or colder indoor environment. Again, warm air moisture-laden air comes in contact with a cold surface, forming condensation. In both cases, this condensation can occur as surface condensation or on surfaces within the interstitial parts of the building, i.e., the inner space of the building envelope.

Interstitial condensation issues were rare in Australian buildings until the 21st century because of lower levels of thermal insulation and airtightness. The building's interior was leaky, well-ventilated externally and did not trap and build up water vapour. With the increased levels of energy efficiency resulting in increased insulation and airtightness, the underlying moisture movement has changed, resulting in less opportunity for the moisture-laden air to escape. The consequence of this is a rise in moisture-related problems in Australian buildings, regardless of the materials used.

Unwanted moisture issues in buildings have also seen a rise in the degree, extent and frequency of mould growth, causing health-related issues for the building's occupants, and is a pivotal contributor to what is commonly referred to as "sick building syndrome". In addition, increased moisture results in possible deterioration of the building structure, an essential consideration for non-durable timber.

Unfortunately, condensation is still perceived by many in Australia as a minor issue despite the Australian Building Codes Board's wide-ranging survey in 2016, which found

Based on the nationwide condensation survey, more than 40% of new buildings have condensation and mould[1].

3.1 Condensation Management and Timber Construction

Condensation is the process used to describe moisture formation on a surface due to moist air coming into contact with a surface at a lower temperature. As cold air cannot retain the same amount of water vapour as warm air, excess moisture is released as condensation. The understanding of why, how and when condensation occurs may assist in a best practice design to mitigate condensation risk.

Five key design considerations and approaches for the avoidance of condensation are as follows.

1. Control moisture during construction and have strategies to dry it out before the structure is sealed or the linings are installed. Refer to WoodSolution Guides No 53[2] and 54[3].
2. During the building's occupation, maintain the temperature of the timber so that it is placed well above the dew point temperature, i.e., structural timber is not to be positioned on the cold side of an external envelope unless positioned where it can safely dry out.
3. Detailed and built to avoid in-service water traps, by the provision of adequate fall, drainage, ventilated cavities, etc.
4. The management of internal humidity levels through effective ventilation strategies to avoid excessively high humid environmental conditions.

In essence, moisture is making its way into or out of a building. The key concept is that the amount of moisture coming into the system (exterior envelope) is less than coming out of the system, so there is a potential to dry; refer to Figure 3. In addition, the moisture should avoid the opportunity of meeting cold surfaces that condense the vapour into a liquid.

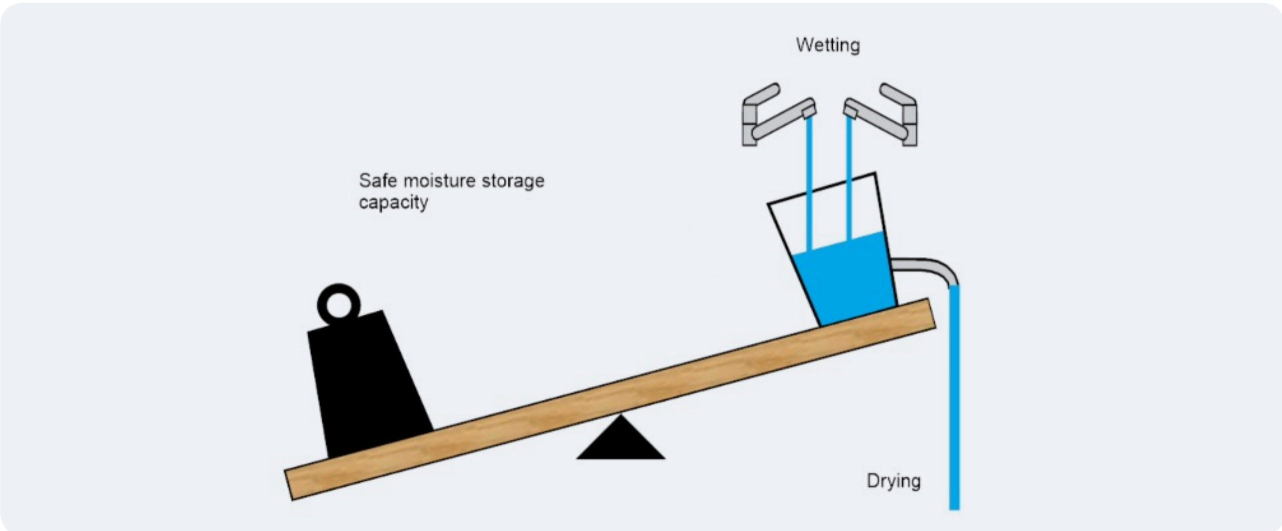


Figure 3: Moisture balance in the exterior envelop of a building

4 Background Information

Understanding the fundamentals of building physics may assist in making correct design decisions. The following is the background to the building physics around condensation and its management.

4.1 Understanding Relative Humidity

Humidity is the concentration of water vapour present in the air. Relative Humidity (RH) measures the amounts of water vapour present in the air relative to the maximum amount of water vapour the air can hold (saturation) at the same temperature, expressed as a per cent. For example, if the relative humidity was 50 per cent, the air is holding half the moisture it could for a given temperature. The warmer the air gets, the more moisture the air can hold.

Figure 4 illustrates that if the amount of water vapour in the air doesn't change, the relative humidity percentage changes as the air temperature increases. As the air gets closer to saturation, this is represented by higher relative humidity. A high relative humidity implies that the air is saturated for the current air temperature.

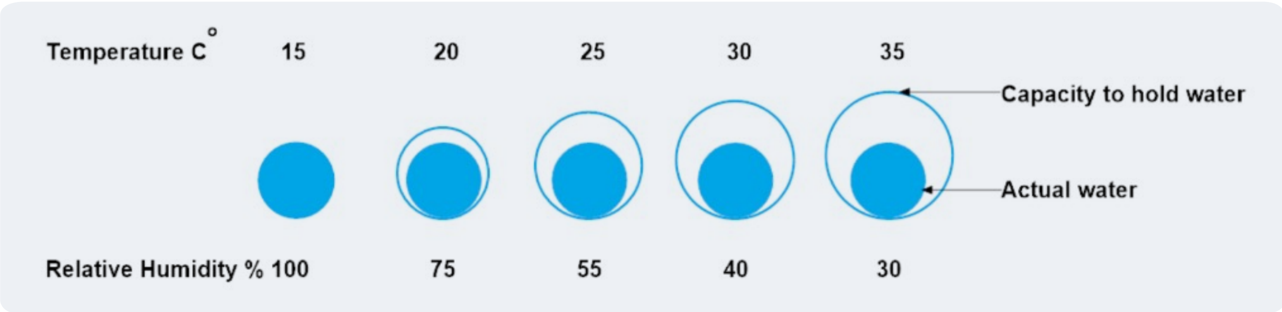


Figure 4: Illustrating Relative Humidity change with temperature

4.1.1 Saturation or Dew Point

The Dew Point is the temperature of air where water vapour within the air becomes saturated or the relative humidity of the air reaches 100%. Any additional cooling causes the airborne water vapour to condense to form liquid water, termed Dew.

Depending on its altitude, condensed water in the air is called fog (ground level) or a cloud. When this saturated air contacts a surface colder than the air, water condenses on the surface, and this condensed water is termed Dew or frost if it freezes; refer to Figures 1 and 2.

4.1.2 Psychrometric Chart

A psychrometric chart represents atmospheric air's physical and thermal properties for particular air pressure in the atmosphere (barometric pressure). The Dew Point temperature can be read off this chart; refer to Figure 5. For example, a typical comfortable room temperature and relative humidity, is 23°C and 50 per cent relative humidity. From Figure 5 below, for a temperature of 23°C and relative humidity of 50 per cent, the Dew Point temperature is 12°C. Therefore, for the ideal room temperature and relative humidity, water vapour condenses when it hits a surface at or below 12°C

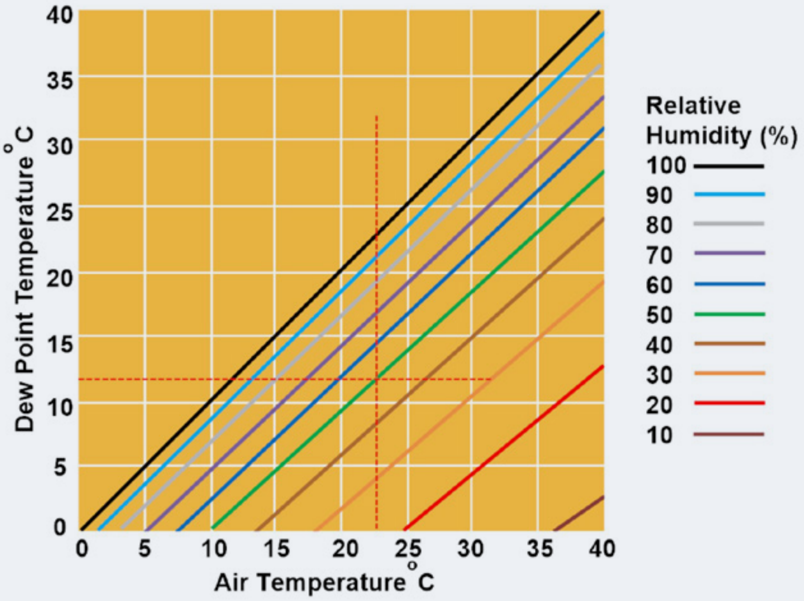


Figure 5: Psychrometric Chart for determining Dew Point Temperatures (Image credit: TDA)[1]

4.2 Water Vapour Diffusion

Water vapour diffusion is the movement of water vapour through vapour-permeable materials. Vapour diffusion happens through a solid material even when the material has no holes. This vapour movement occurs when there is a partial vapour pressure difference between the two sides of the material. Water vapour will attempt to diffuse through the material from the side at high vapour pressure to the side at low vapour pressure, irrespective of air pressure. The diffusion direction in a building envelope is often from the warm to the cold side but does not need to be the case in all situations.

Diffusion is possible because water vapour is a cluster of small water molecules that can get through the material's pores or openings. The material is considered air and watertight when liquid water molecule clusters are too large to pass through openings or pores. It is also possible to have diffusion through these materials where purpose-placed holes are made in materials to allow for controlled vapour movement. Various building materials have different diffusion rates, and Figure 6 illustrates the range of various common building materials. Materials such as glass or metals are considered impermeable.

In practice, diffusion through materials is rarely the dominant way the water vapour travels within the building fabric. Most water vapour will move with air through accidental or intentional gaps and holes where air pressure differential driven air carrying vapour is dominant.

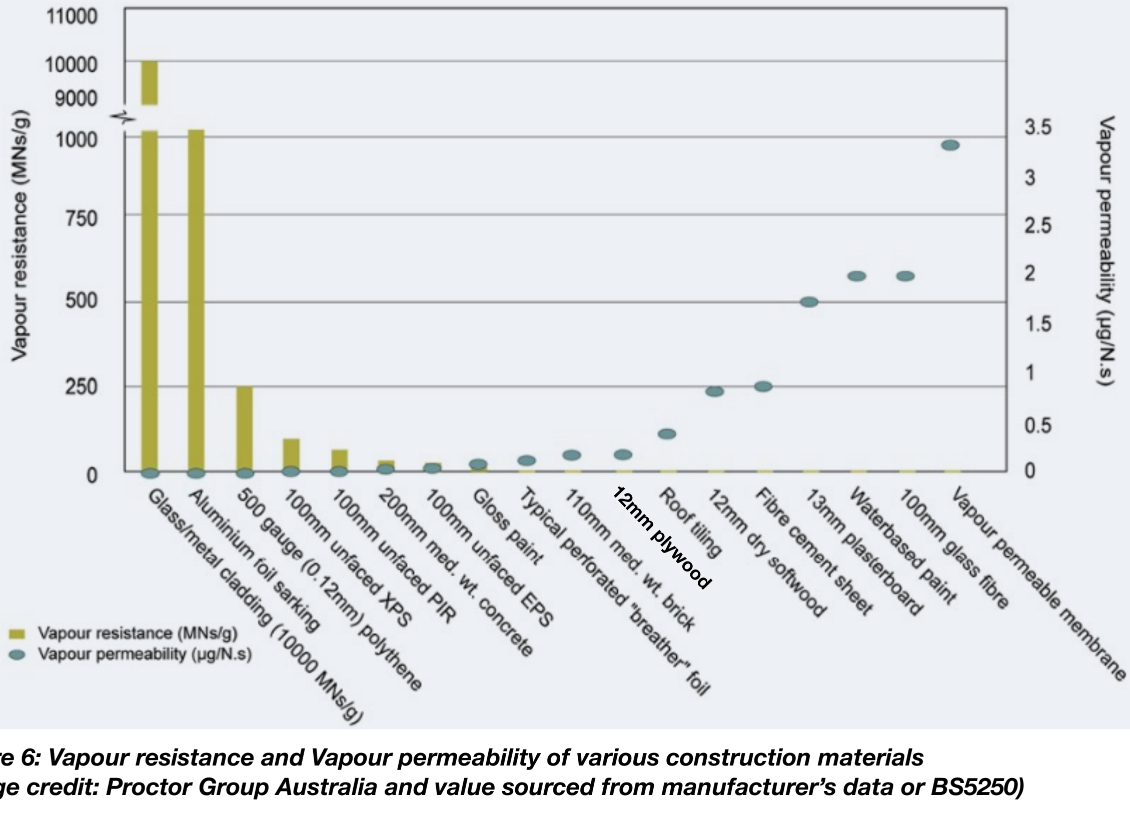


Figure 6: Vapour resistance and Vapour permeability of various construction materials (Image credit: Proctor Group Australia and value sourced from manufacturer's data or BS5250)

4.3 Why Manage Condensation in Buildings

The two primary considerations for moisture within a building are the occupants' health and the degradation of the materials used in construction. The following discusses both.

4.3.1 Health Implications of Dampness in Buildings

Based on the Victorian Government Better Health , mould associated with damp buildings can trigger nasal congestion, sneezing, cough, wheezing, respiratory infections and worsen asthma and allergic conditions.

People who are more susceptible to these symptoms and other serious health effects include those with:

- weakened immune systems
- allergies
- severe asthma
- chronic, obstructive, or allergic lung diseases.

4.3.2 Building Materials and Components Degradation

In addition to causing health problems, excessive moisture can damage building materials and components; for example,

- Prolonged damp conditions can lead to moulds and bacteria colonising building materials and HVAC systems
- Damp conditions attract termites
- Chemical reactions with building materials and components can cause structural fasteners, wiring, metal roofing and conditioning coils to corrode
- Adhesive failure in flooring or wallboards
- Water-soluble building materials (e.g., plasterboard) can dissolve
- Timber and wood-based elements can expand and rot
- Brick or concrete can be damaged by sub-surface salt deposition
- Paints and timber finishes can be damaged
- The insulating value (R-value) of thermal insulation can be reduced.

5 Condensation Requirements Contained in National Construction Code

The following discusses the National Construction Code (NCC)[4] Performance Requirements and methods to demonstrate compliance through verification or Deemed-to-Satisfy pathways for condensation management within a building.

5.1 NCC Performance Requirements

The National Construction Code [4] has a performance requirement that the sole occupancy unit (apartment) of Class 2 or 4 buildings and Class 1 (houses) must manage the risk associated with water vapour and condensation to minimise their impact on the occupant's health. The intent is to safeguard occupants from illness or loss of amenities due to excessive internal moisture build-up that may cause mould or the deterioration of building elements.

The NCC already requires weatherproofing from the outside, specifically, the Objectives in Volume One F101 (Class 2 to 9) and Volume Two H201 (Class 1). This weatherproofing requirement is for the roof and external wall. Again, it involves preventing water ingress that may cause occupant health issues or deterioration of building elements, similar to the condensation objective.

In simple terms, weatherproofing requirements are for direct liquid water penetration, while condensation requirements are for water vapour, a logical partnering of water management of a building. The NCC condensation requirement recognises that the rise in insulation and airtightness has changed the underlying building performance. "Less energy flow through the building fabric also means less moisture flow, so when the fabric gets wet, it is likely to stay wet longer" [5]. Therefore moisture can't get out of the building and may accumulate on the interior side of the weatherproofing layer, negatively impacting occupants' health or the deterioration of building elements.

5.2 NCC Compliance

Besides an independently developed performance solution, the NCC has two means of compliance; a computer modelling verification method or Deemed-to-Satisfy (DTS) - prescriptive method. The methods are identical in NCC Volume One and Two, and the following discusses both options.

5.2.1 Verification Method

The NCC provides a Verification method that allows computer modelling to substantiate that the performance requirements have been met. In simple terms, the modelling aims to show that mould is limited to acceptable levels at two locations depending on the construction of the exterior walls. These locations are on the interior surface side of the water control layer (exterior cladding or membrane used to prevent water ingress) or the surface of building's structural elements and components on the interior side of the water control layer. It only applies to the sole occupancy unit (residential space) of an NCC's Class 1, 2 or 4 building.

Acceptable mould level is when the mould index is calculated to be 3 or less. The mould index is calculated from Section 6 of AIRAH DA07 [6] using the Standard's design inputs, including the intermediate method for calculating indoor design humidity.

5.2.2 DTS Provisions

The DTS provision has three requirements: when a pliable building membrane is used, the air extraction from the building's area that produces moisture, and the ventilation requirements for roofs in Climate Zones 6, 7 and 8. These requirements are explained in the following.

Use of suitable pliable building membranes.

The NCC has specific DTS provisions for sole occupancy units of Class 2 or 4 parts of a building or Class 1 building. The DTS specifies that where a pliable building membrane is used in an external wall, it must

- Comply with AS/NZS 4200.1 [7] - An Australian Standard sets out the minimum requirements for materials for use as pliable building membranes.
- Be installed in accordance with AS 4200.2 [8] - An Australian Standard that sets out requirements for the installation of pliable building membranes
- Be a vapour-permeable membrane
  - Climate Zones 4 and 5 – vapour permeance no less than 0.143 µg/Ns (Class 3 and Class 4 vapour control membranes as defined by clause 5.3.4 of AS 4200.1 meet this vapour permeance requirement)
  - Climate Zones 6, 7 and 8 – vapour permeance no less than 1.14 µg/Ns (Class 4 vapour control membranes as defined by clause 5.3.4 of AS 4200.1 meet this vapour permeance requirement)
- Be located on the exterior side of the primary insulation layer of wall assemblies

Where a pliable building membrane is not installed in an external wall system, except for single-skin masonry and concrete, the weatherproofing is assumed to be provided by the exterior cladding. Where this is the case, a drainage cavity is required on the inside of the exterior cladding and must be separated from water-sensitive materials like timber, wood panels, plasterboard, glasswool insulation, etc. Therefore, a pliable building membrane is required when cladding is directly fixed to a timber substrate.

Furthermore, the NCC and referenced standards include several clauses that state where sarking or pliable building membranes are required, for example, building in bushfire-prone areas, energy efficiency, and tiled roof construction. Care is required that the above vapour-permeable requirements for sarking or pliable building membranes are also used.

Exhaust ventilation

The DTS also has requirements for installing exhaust systems in the kitchen, bathroom, toilet area, and laundry. The minimum exhaust flow rate required varies for the type of area being vented,

- 25 L/s for a bathroom or sanitary compartment; and
- 40 L/s for a kitchen or laundry.

The discharge must be via a duct or shaft to the outside of the building. There is no allowance for discharge into a roof space.

Ventilated Roof Spaces

Roofs in Climate Zone 6, 7 and 8, mainly in the southern parts of Australia (refer to Section 6 of this Guide), must have roof space for ventilation purposes. Locations include

- immediately above the primary insulation layer; or
- immediately above sarking with a vapour permeance of not less than 1.14 µg/N.s (Class 4 vapour control membrane as defined by clause 5.3.4 of AS4200.1), which is immediately above the primary insulation layer; or
- immediately above ceiling insulation which meets the requirements of certain energy efficiency requirements

The roof space must have a height of not less than 20 mm, and be ventilated to outdoor air through evenly distributed openings determined by roof pitch and if the roof has a cathedral ceiling. Minimum ventilation opening area must be in accordance with Table F8D5 (volume 1) and Table 10.8.3 (Housing Provisions)

that vary due to the roof pitch,

- $< 10^{o}$ - 25,000 mm^2/m provide at opposing ends of the roof space.
- $\geq 10^{o}$ and $< 15^{o}$ - 25,000 mm^2/m provided at the eaves and 5,000 mm^2/m at

a high level, i.e. ridge or high side of the roof.

- $\geq 15^{o}$ and $< 75^{o}$ - 7,000 mm^2/m provided at the eaves and 5,000 mm^2/m at

a high level, i.e. ridge or high side of the roof. Where the roof has a cathedral ceiling, an additional 18,000 mm^2/m is required at the eaves.

These requirements do not need to be complied with if the roof is made from concrete or Structural Insulating Panels (SIP) or if the roof is for a Bushfire Attack Level FZ in accordance with AS 3959. It is also not required for an unsarked tiled roof.

5.3 Beyond NCC Minimum Construction Requirements

The NCC provides minimum construction requirements to assist in mitigating condensation risk. Condensation issues may be broader than the NCC minimum requirements, affecting other building types and climate zones. Additional building types include schools, offices, hotels, assisted living and so on, irrespective of the materials that are used within them. Therefore, it is recommended that condensation management be considered wherever moisture can be generated within a building (refer later for discussion on moisture sources). Consequently, the details discussed in this guide are intended for all buildings containing an enclosed space and where moisture is likely to develop in the building's interior, irrespective of the Climate Zone or the NCC's limited range of building types.

Furthermore, the DTS provisions explicitly state that if a pliable building membrane is contained within a wall assembly, it must be located on the exterior side of the primary insulation layer.

For mass timber construction, additional insulation is often placed on the exterior side of the pliable building membrane that may seem to conflict with this requirement. In these cases, the mass timber itself should be considered the primary insulation layer because of its excellent insulation performance and significant contribution towards total R-value.

5.3.1 Further Reading

The ABCB Condensation in Buildings Handbook[9] is an excellent place to start for designers looking for local climatic and regulatory perspectives. However, a broader reading of international guidance is suggested, and further reading is included in Appendix B.

6 Climate

When considering condensation management, water vapour is found in the building from two different sources: the outdoor environmental conditions, i.e., climate and weather, and the other, the conditioned interior of the building. The indoor and outdoor environments are inextricably linked as the interior space needs to be provided with outside air to maintain healthy conditions for occupants.

6.1 Outdoor Climates

The Köppen climate classification is one of the most widely used climate classification systems. German-Russian climatologist Wladimir Köppen first published it in 1884. The Köppen climate classification divides climates into five main groups, each group being divided based on seasonal precipitation and temperature patterns. The five main climate types are:-

- Cold climates (continental) – These regions have warm to cool summers and very cold winters. Humans will feel too cold under outdoor conditions for most of the year.
- Temperate climates – In this zone, there are typically warm and humid summers with thunderstorms and mild winters. There is not enough heat in the coolest season and too much in the warmest season, although neither condition is very severe.
- Hot, dry climates – where excessive heat outdoors is tempered by a relatively dry atmosphere which allows effective evaporative cooling of the body. Significant falls in overnight temperatures also relieve hot daytime conditions.
- Warm, humid climates (tropical) – where outdoor heat is usually less severe than in hot, dry climates, but high humidity levels limit the potential for evaporation. Small diurnal (day-night) temperature variations mean that warm conditions persist overnight.
- Polar – extremely cold. This climate is not relevant to Australia.

6.1.1 NCC Climate Zones for Thermal Design

The NCC has developed eight Climate Zones for energy efficiency considerations that generally involve subdividing the four fundamental Climate Zones that affect Australia, discussed above. Each climate zone is divided into two subsets; refer to Figure 7. This subdivision of fundamental climate types reflects the differences in temperature and insulation requirements for energy efficiency requirements. They are:

Climate Zone 1: Warm, humid type with hot summer
Climate Zone 2: Warm, humid type with mild summer
Climate Zone 3: Hot, dry climate with warm winter
Climate Zone 4: Hot, dry climate with cool winter
Climate Zone 5: Temperate climate with warm temperate designations
Climate Zone 6: Temperate climate with mild temperate designations
Climate Zone 7: Temperate climate type with cool temperate designations
Climate Zone 8: Cold climate

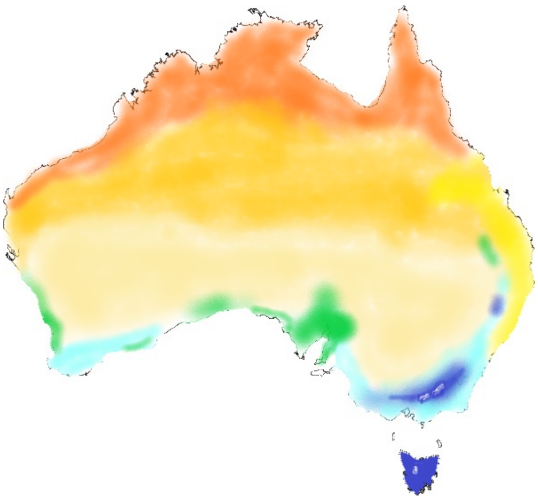


Figure 7: NCC Climate Zones (Based on ABCB Condensation Handbook Image credit: TDA)

6.1.2 Indoor Climate and Moisture Sources

For unconditioned indoor environments, and as a minimum, water vapour levels indoors are generally the level of outdoor water vapour levels. This minimum is due to the air exchange that is required to keep the indoor environment healthy.

Additional water vapour comes from sources such as cooking, clothes drying and showering; refer to Table 1 and Figure 8. Also, water vapour can come from the occupant's transpiration and breathing, i.e. people and pets. The NCC commentary [10] states, "human occupation of a residential building creates approximately 10 litres of water vapour per day. In an average family home with two adults and one child, this equates to 30 litres of water vapour within the built fabric per day."

The amount of water retained in the indoor environment depends on natural and mechanical ventilation. For example, cooking, showers and clothes driers generally have a dedicated exhaust. However, if the exhaust is only to the roof or other cavity, this may not reduce the water content as much as exhausting to the outside. Eventually, this exhausted water vapour may return to the interior spaces.

Table 1: Sources of water vapour inside a residence.

Source	Water	Assumption
Cooking - electric	5 kg/ day	Used for 2 hours per day
Cooking – gas	7 kg/day	Used for 2 hours per day
Cloth Washing	0.5 kg	per load
Dishwashing	1 kg per day	
Bathing/Showering	1.5 kg per person	Not vented
Occupants	0.2 kg per hour per person	
Gas heating	0.5 to 1 kg per day	Unflued

Note: Information from ABCB Condensation Handbook

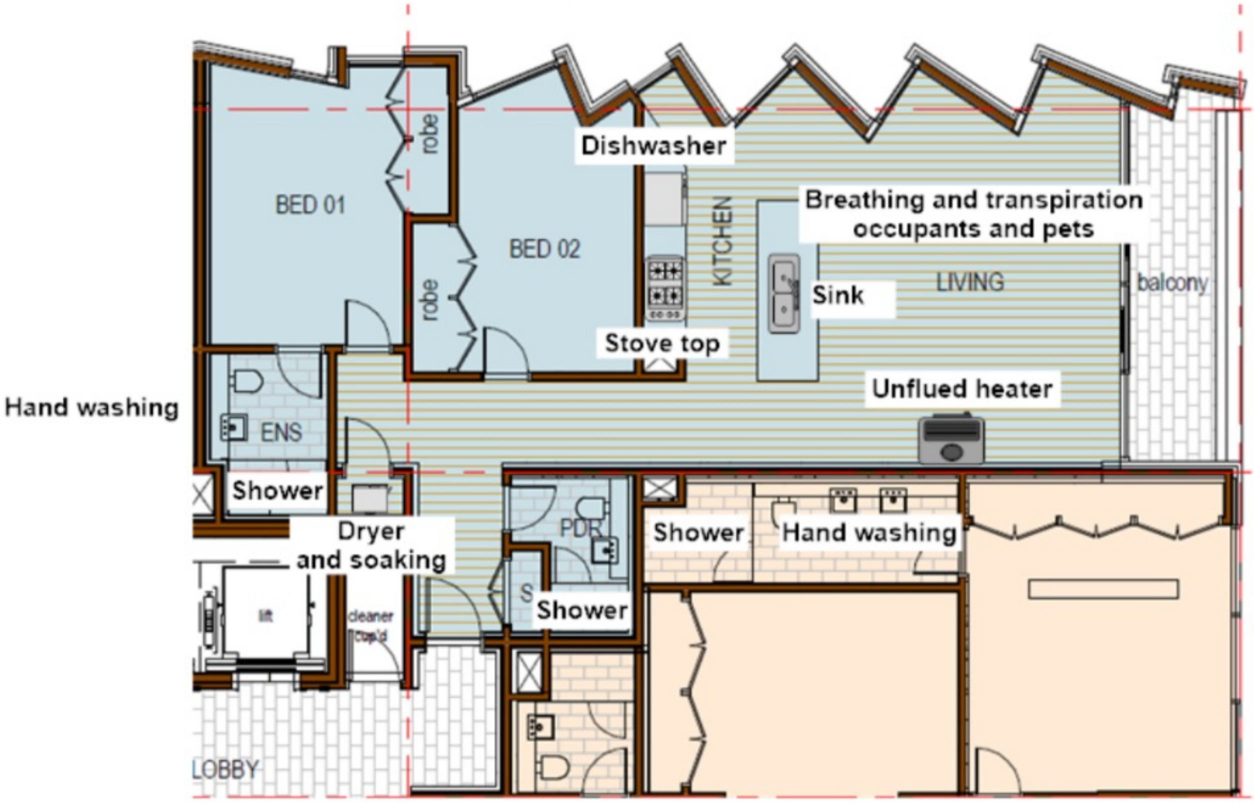


Figure 8: Source of Water Vapour (Based on ABCB Condensation Handbook)
(Image credit: Zimmermann Design Studio, studio505 and TDA)

6.1.2.1 Condensation Potential

The Bureau of Metrology provides historical weather data, where dew point, maximum and minimum, extreme, and minimum temperatures are recorded. Considering this information can indicate when Dew is likely to form. The two common scenarios that should be considered are when the moist warm air is caused by the interior of the building, i.e. heated environments in winter, and the other from the exterior environment, i.e. moist warm air from summer or tropical conditions.

6.1.2.2 Indoor Air Environment Potential to Cause Condensation

The following Figures 9 to 15 indicate the likelihood of the formation of condensation in a building envelope for various major urban regions of Australia for various months throughout the year. Where warm moist air generated from the interior building meets the exterior environment at a Dew point temperature below 12°C, condensation may occur. Two types of low temperatures are considered: mean and record low temperatures. Considering only the mean temperatures, disguises condensation potential occurring outside the mean temperatures, and in most instances, for most parts of the year.

The indoor environment is assumed to be conditioned at 50 per cent Relative Humidity and has an air temperature of 23°C. From the Psychrometric Chart, Figure 5 produces a Dew Point temperature of 12°C. To read the graphs in Figures 9 to 15, any temperatures below the Dew Point temperature of the indoor air, shown as a green dash line and shaded area, can produce condensate within the building's envelope if a cold impermeable surface is met. The extreme outdoor minimum record temperatures are included to show that condensation is still possible beyond mean conditions, indicating that condensation consideration is an all-around issue for some regions of Australia.

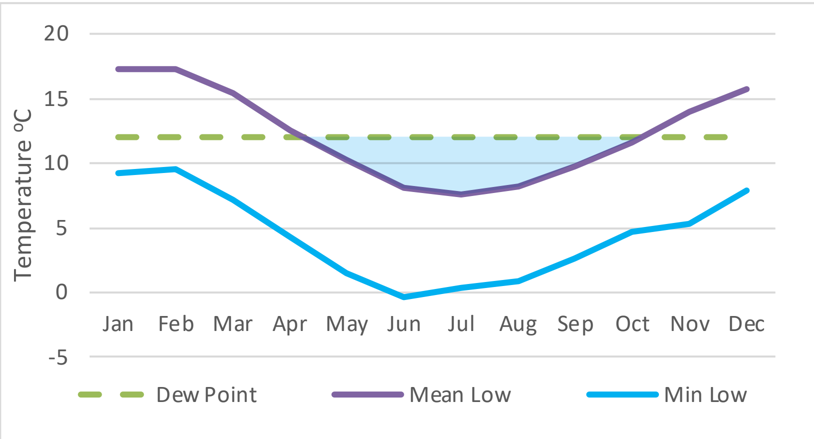


Figure 9: Adelaide (Kent Town) – Climate Zone 5

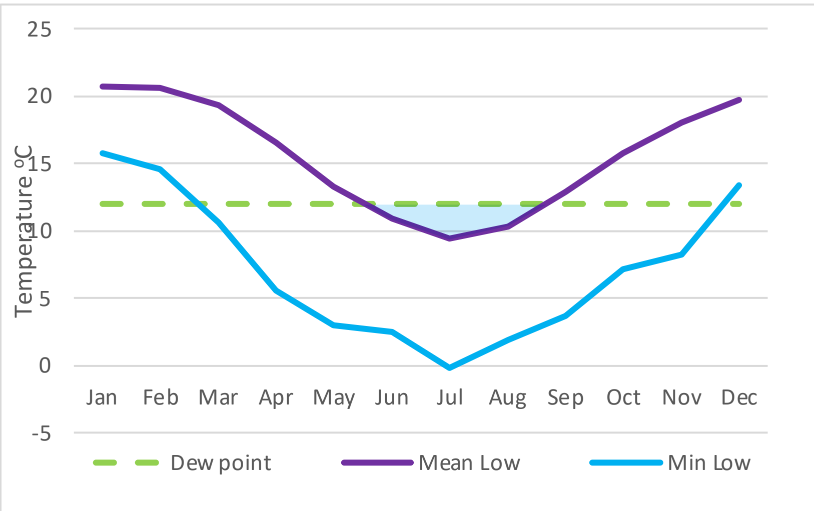


Figure 10: Brisbane (Brisbane Regional Office) – Climate Zone 2

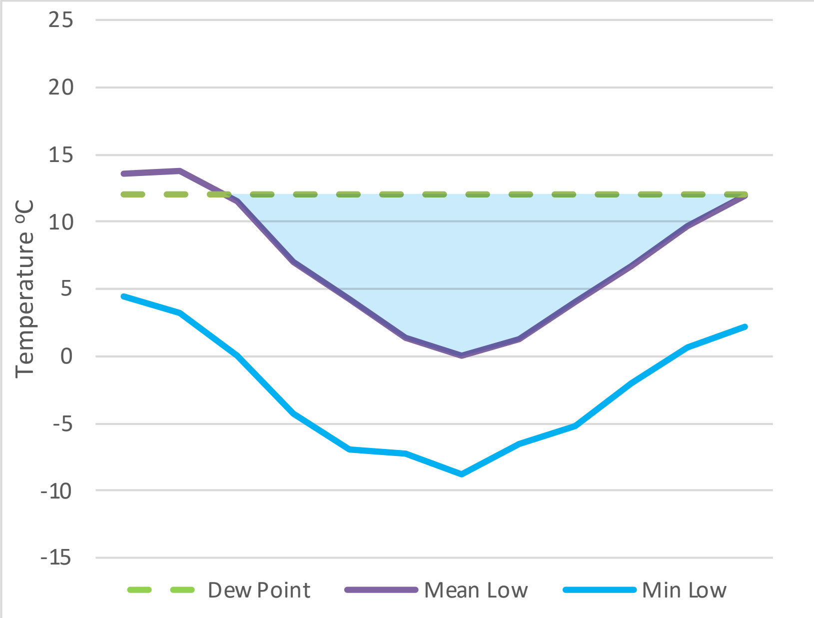


Figure 12: Canberra (Canberra City) – Climate Zone 7

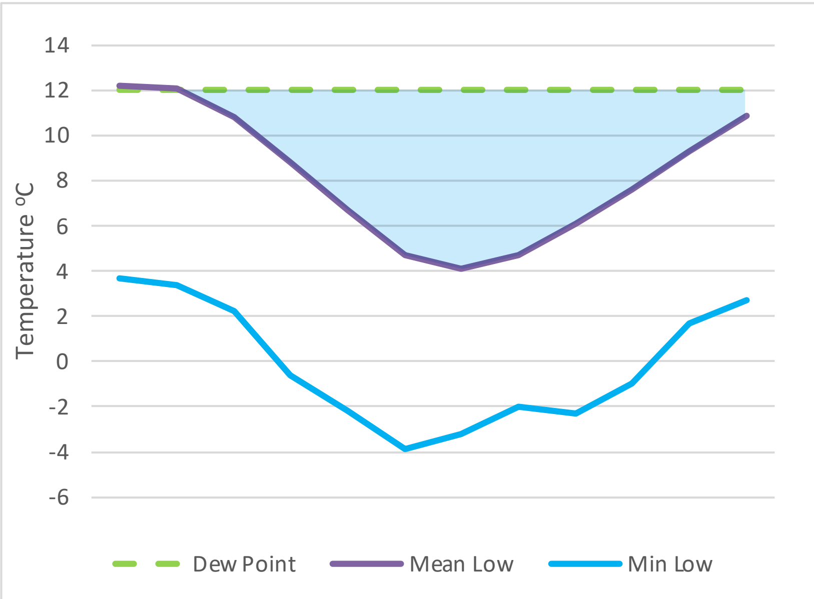
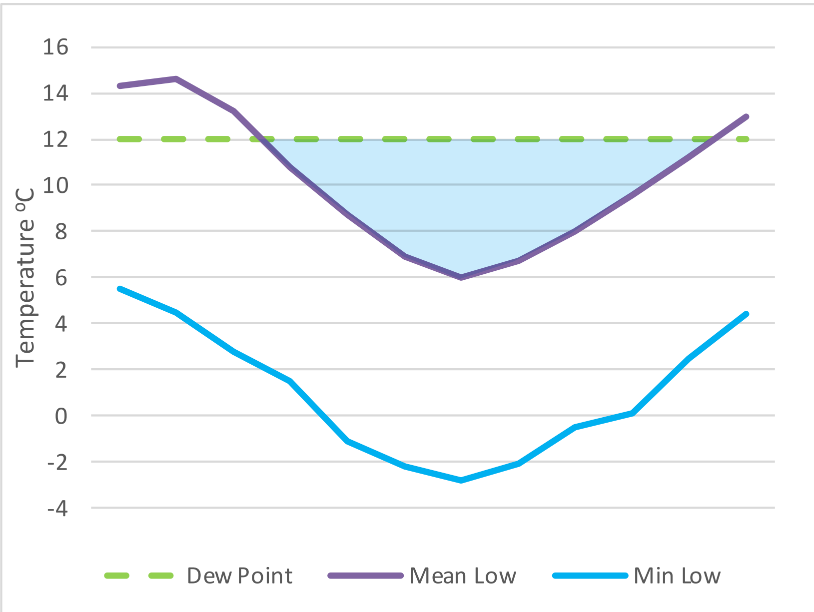


Figure 13: Hobart (Regional Office) – Climate Zone 6



Melbourne (Regional Office) – Climate Zone 6

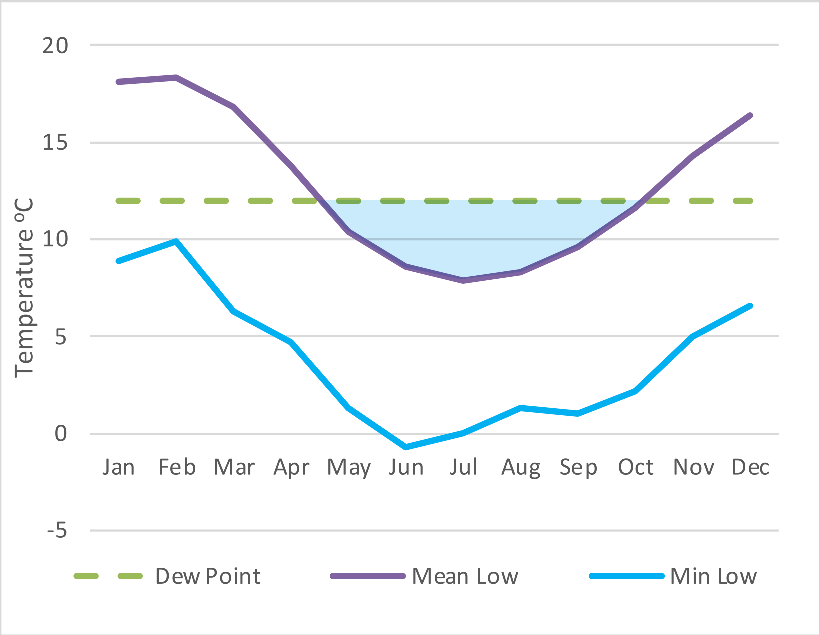


Figure 14: Perth (Perth Metro) – Climate Zone 5

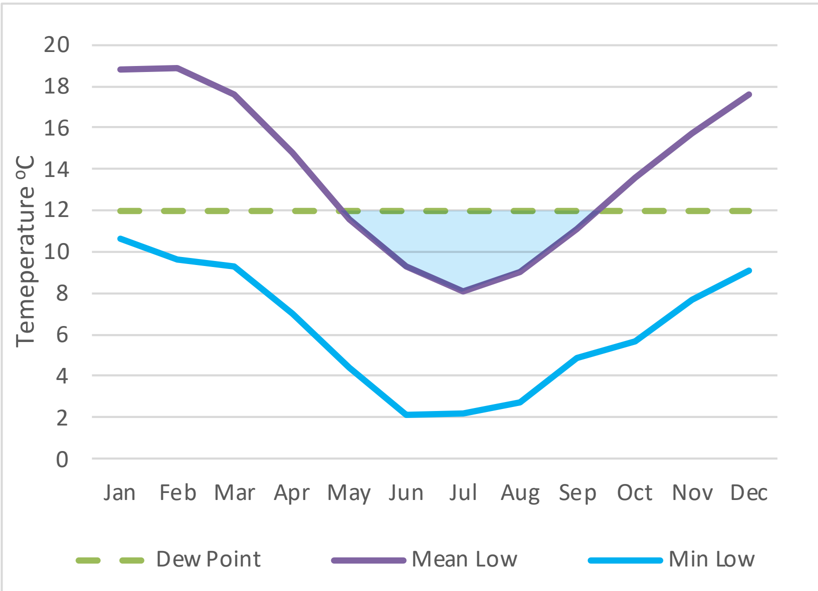


Figure 15: Sydney (Observatory Hill) – Climate Zone 5 (Sydney East)

6.1.2.3 Exterior Air Environment Potential to Cause Condensation

Summer temperature is rarely an issue; however, occasionally, where the indoor space is air-conditioned, the environment does cause an opportunity for condensation to form. Figures 16 to 22 illustrate the likelihood of the formation of condensation in various regions of Australia with respect to moisture from the exterior environment for various months throughout the year and the monthly mean outdoor dew point as a guide. An interior condition temperature is assumed at 19ºC.

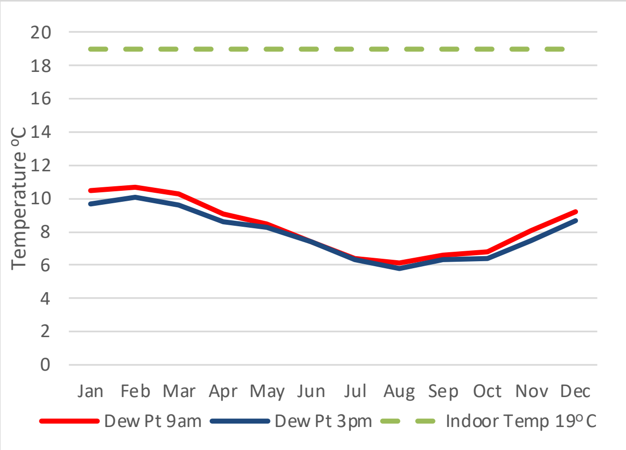


Figure 16: Adelaide (Kent Town) – Climate Zone 5

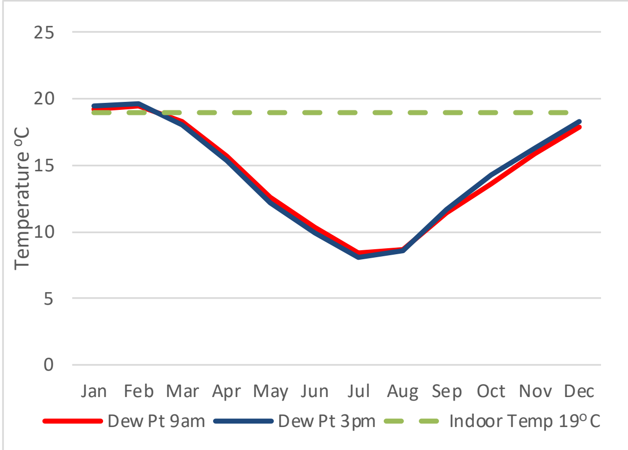


Figure 17: Brisbane (Brisbane Regional Office) – Climate Zone 2

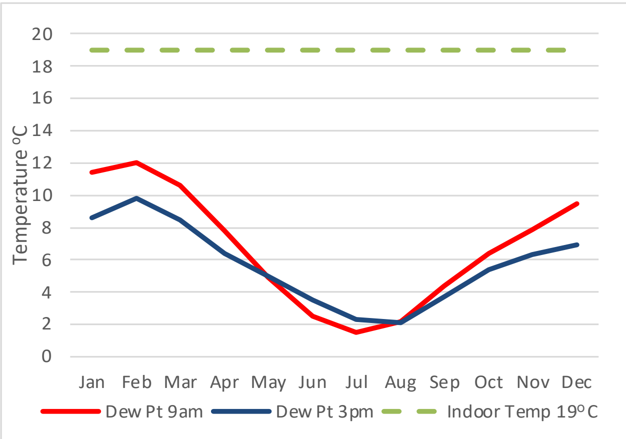


Figure 18: Canberra (Canberra City) – Climate Zone 7

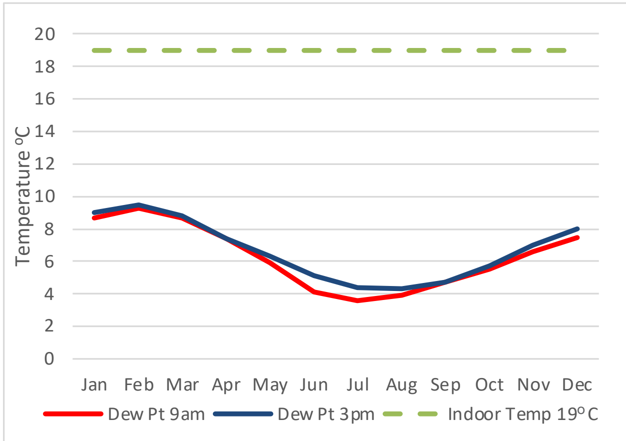


Figure 19: Hobart (Ellerslie Road) – Climate Zone 7

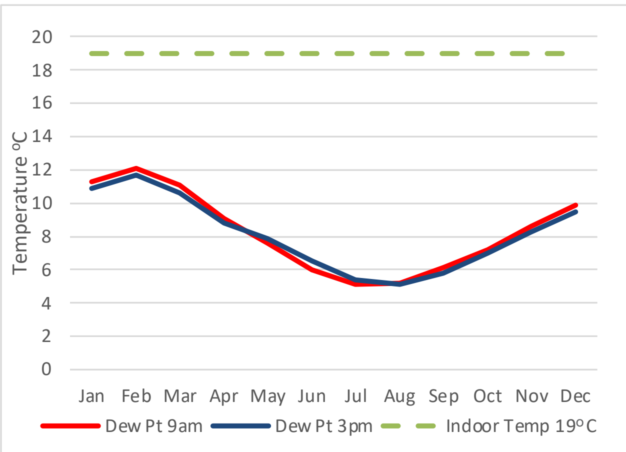


Figure 20: Melbourne (Regional Office) – Climate Zone 6

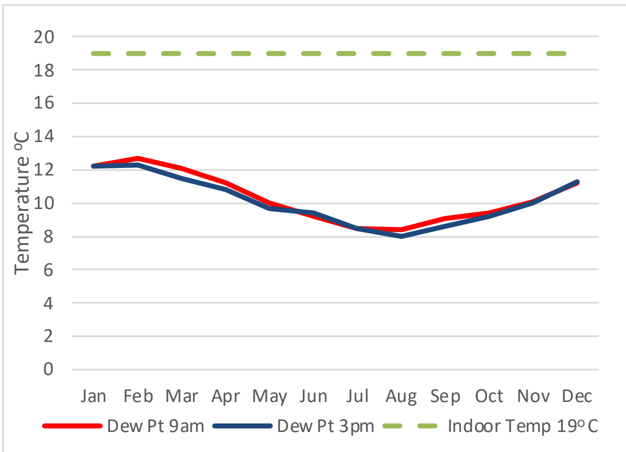


Figure 21: Perth (Perth Metro) – Climate Zone 5

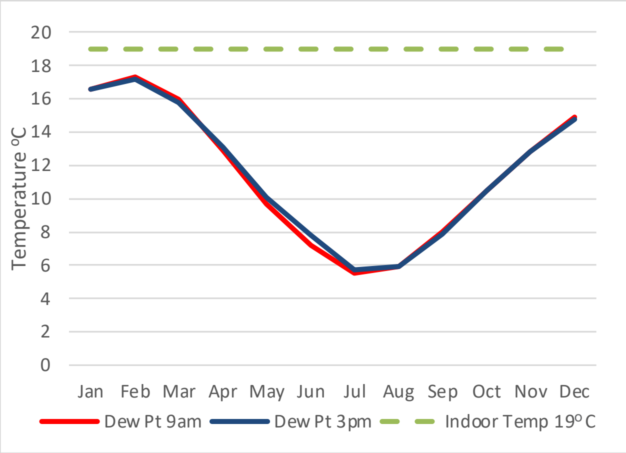


Figure 22: Sydney (Observatory Hill) –
Climate Zone 5 (Sydney East)

In summary, the winter temperature dominates condensation potential. In some environments, the mean temperature indicates that it is less likely to form condensation; however, when extreme temperatures are considered, the condensation potential increases in most cases. For summer conditions, condensation issues are more likely in hot, humid climates, such as in Darwin, illustrated in Figure 23.

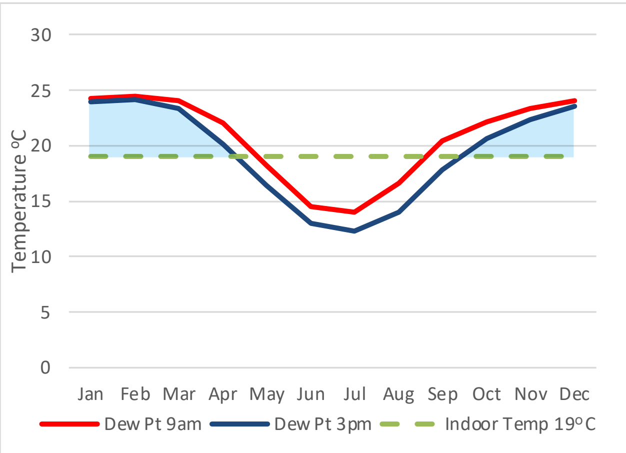


Figure 23: Darwin Airport – Climate Zone 1

7 Control of Moisture during Construction

The average moisture content of timber during the various seasons is termed the Equilibrium Moisture Content (EMC). For Australia's major urban areas, this Equilibrium Moisture Content is generally 12 per cent, and seasoned timber is often targeted for this moisture content to minimise shrinkage and expansion movements within the finished building.

Timber can safely absorb some moisture during construction; however, long-term exposure to moisture may affect the timber's stability and finish or facilitate mould growth. As the building is enclosed, the interior of the building dries. For relatively thin timber elements, like studs and wood panels, the construction period is generally long enough for these elements to dry out. However, mass timber products take longer to dry as they are thicker in size. This extended drying period may also be needed for thin timber elements, like studs and wood panels, where they have been subjected to excessive rain. Therefore to minimise mould growth and improve the performance of the building, managing the water exposure during construction will assist in this outcome.

WoodSolution Guides No 53[2] and 54[3] provide details regarding moisture management during construction and should be read in conjunction with this guide. However, two principal activities can be employed to minimise the moisture ingress into timber elements during construction, and one is to avoid or reduce water entering the building. The other is to cover the timber element to minimise moisture ingress. The following briefly discusses strategies to achieve this.

7.1 Stormwater Management

Erecting a building means exposing it to direct weather during the construction phase. Timber is capable of withstanding the occasional wetting; however, prolonged exposure to moisture may cause damage. It is recommended that building sites, irrespective of the size of the project, have a stormwater management plan that deals with water, irrespective of the source.

Ideally, water is prevented from pooling and is able to drain away from the building. Achieving this requires the placement into the working deck, a means of shedding the water away from the building by temporary pipes or channels; refer to Figure 24. Where ponding of water cannot be prevented, the working deck of the structure should be cleared of water by broom, squeegeeing or other means as soon as possible.

Figure 24: Temporary stormwater downpipes (Image credit: Rotho Blaas).

7.2 Coating or Covering of Timber

Water-resistive barriers that are vapour permeable or temporary waterproofing methods can greatly assist in protecting the timber during construction. These can be membranes or applied coating, which can be applied in the factory before delivery. Their primary purpose is to deflect rain; the timber element may still absorb the water when water is allowed to pool. Also, these water-resistive barriers won't prevent moisture contained in the air from altering the timber's moisture content.

Where vapour permeable membranes are used to protect the timber during construction, it is recommended that they are light in colour, as dark colours retain heat. Any temporary vapour impermeable membrane protection layers need to be removed following the sealing of the building. However, vapour-permeable water-resistive barriers can remain where they offer post-construction long-term functionality. Impermeable membranes must not be used.

Due to the end grain's sensitivity of timber to moisture, panel joint treatment and protection of panel edges should be a priority. Joints can often be shielded by vapour permeable tape application or by sealing splines; refer to Figure 25.

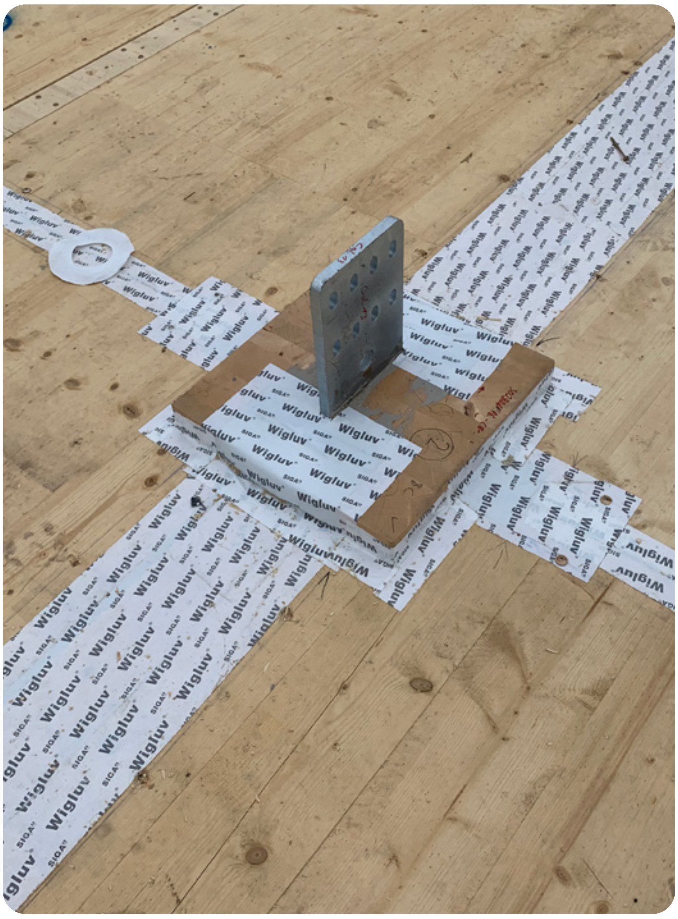


Figure 25: Tapes sealing joint in timber floor (Image credit: TDA)

7.3 Moisture Content of Timber Substrate Prior to Installing Coverings to Claddings

Good building practice and an assumption to the modelling used is that the moisture content of the timber substrate is 15 per cent or lower before the installation of covering or cladding. For further information on strategies to keep timber substrates dry or methods of drying timber substrates, refer to WoodSolutions Guide No 53[2] and 54[3].

8 Maintain the Temperature of the Structural Timber above Dew Point Temperature

Although timber as a material is a good insulator, significantly better than other forms of construction such as concrete, masonry or steel construction, a timber-based system may still need the addition of thermal insulation to meet the minimum energy efficiency requirement of the NCC. However, the incorrect placement of insulation or the use of the wrong type of membrane can lead to condensation. Therefore the strategy employed to prevent this is to consider;

- The placement of external insulation to keep the moisture-sensitive materials above dew point as they are no longer cooled by outdoor temperature, and
- The use of vapour open materials that allow for drying.

8.1 Wood-Based Solutions Considered – NCC Verification Method

The NCC provides a Verification method that allows computer modelling to substantiate that the performance requirements have been met. In simple terms, the modelling aims to show that moisture will not accumulate on the interior side of the exterior cladding or a pliable membrane used as the waterproofing of the exterior envelope and that mould will not grow.

Several wood-based systems roof and wall systems have been modelled by Fabricfirst, who have used the WUFI® software suite, a standard program for evaluating moisture conditions in building envelopes, considering four climate zones within Australia. The assumptions used with the evaluation are as follows:-

- ACH (Indoor) = to be based on 0.35 ACH to represent typical construction quality, window openings and general air leakage or a reasonable level of continuous mechanical ventilation
- Building Volume = 366 m^3, based on 140 m^2 total conditioned area
- AC Type: Air conditioning
- Bedrooms: 3

The modelling conforms to the NCC Verification method. A discussion on the assumptions and criteria to demonstrate meeting the NCC performance requirement is found in Appendix A.

This guide considers two forms of construction; lightweight timber framing and mass timber. The strategies for each vary and are dealt with separately. In addition, the solutions presented are grouped into construction that is likely for housing, low-rise commercial building and buildings that use the NCC's fire-protected timber concession. In essence, the difference is the inclusion of fire-resistance construction. For the low-rise mass timber buildings that do not use the fire-protected timber concession for NCC compliance and require fire-resisting to the external walls, the assumption is that the fire resistance is obtained from the mass timber.

8.1.1 Climate Zones

This guide provides solutions for walls and roofs, for four climate zones, based on the NCC's Climate Zones for Thermal Design; refer to NCC for a definition of Climate Zones. The Climate Zones for Thermal Design considered are Zones 2, 5, 6, and 7. They represent major urban areas of Australia and include: -

- Climate Zone 2 – Brisbane (includes the coastal area from Port Macquarie (NSW) to Mackay (Qld))
- Climate Zone 5 – Adelaide, Perth and Eastern Sydney and their surrounding areas.
- Climate Zone 6 – Western Sydney, Melbourne (includes the coastal zone from Wollongong (NSW) around the South East of Australia to Adelaide and a region around Albany (WA))
- Climate Zone 7 – Hobart and ACT (includes the highland regions of Tasmania, Victoria and NSW)

The tropical north - Climate Zone 1 and Alpine - Climate Zone 8 are not considered in this guide and should be designed separately by a specialist. For Climate Zones 3 and 4, there is no verification undertaken. For these zones, an indicator of performance is if the system is adequate for Climate Zone 2 and 5, it should be suitable for Climate Zones 3 and 4.

8.1.2 Lightweight Timber-Frame

For most framed wall systems, the insulation generally is placed with the frame and protected by a pliable building membrane. However, care needs to be taken to ensure these pliable building membranes are not subject to condensation forming on their inner face. This condensation can lead to water forming on structural members like timber framing and can lead to problems with the growth of mould and mildew. Figure 26 illustrates this, where the red line indicates the temperature gradient through the building envelope, in this case, an exterior wall. The blue dotted line indicates the Dew point temperature, and when these lines cross condensation forms. In Figure 26, condensation that forms within the timber framing is likely to cause mould growth and deterioration of the timber.

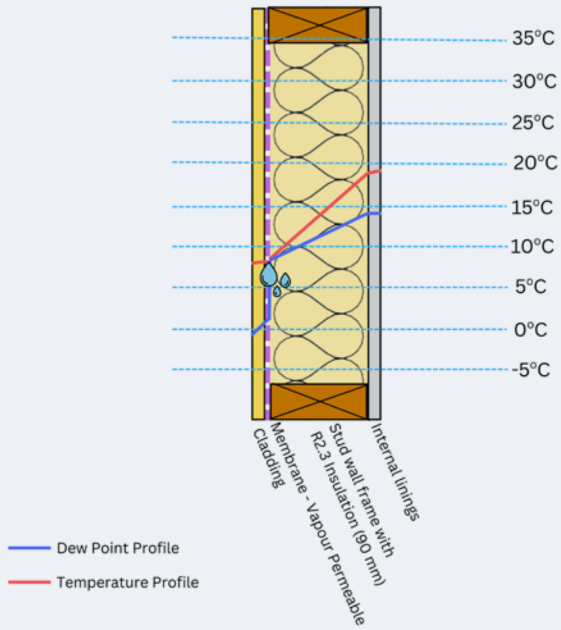


Figure 26: Condensation forming within timber framing (Image credit: TDA)

A way to address this issue is to use construction that allows water vapour diffusion, not air, through the wall or roof fabric. The intent is to allow the flow of water vapour from the building's high [vapour pressure] humidity interior to the lower [vapour pressure] humidity exterior. The water vapour should not be restricted by the pliable building membrane and can safely escape through the outer layers of the wall or be removed in ventilated and drained cavities more quickly than it enters through the inner layers. A drainage cavity, often located next to the exterior cladding, is required as the exterior cladding is often impermeable to moisture. Figure 27 illustrates that the temperature profile through the exterior wall envelope is warmer than the Dew point temperature, preventing condensation from forming.

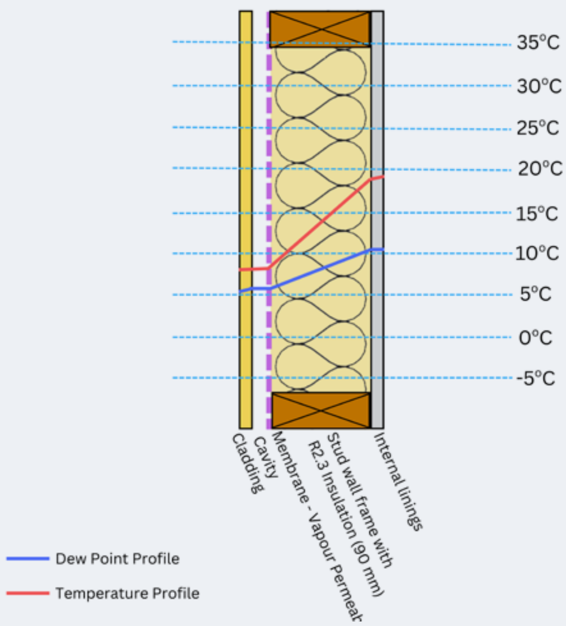


Figure 27: Lightweight timber-framed wall with a cavity (Image credit: TDA)

8.1.2.1 Timber-Framed Wall Solution for Various Climate Zones

Table 2 describes various timber-framed wall systems for cavity construction, and Table 3 is for direct fixed cladding. Table 4 is for various roof systems for four Climate Zones utilising timber-framed systems. Refer to Appendix A for more information on the modelling conducted to achieve this recommendation and the assumptions used.

Not all construction systems apply to all climate zones. Where this occurs, the system may still be adequate if additional elements are added or increased drying potential is incorporated. In these situations, it is beyond the scope of this guide, and independent modelling and advice should be sought.

Furthermore, where additional plasterboard or difference thickness is required within the system for increased fire resistance, adding the plasterboard is likely not detrimental to the system's performance.

Table 2: Solution for Housing and Low-rise Buildings – Timber-Framing Cavity Construction

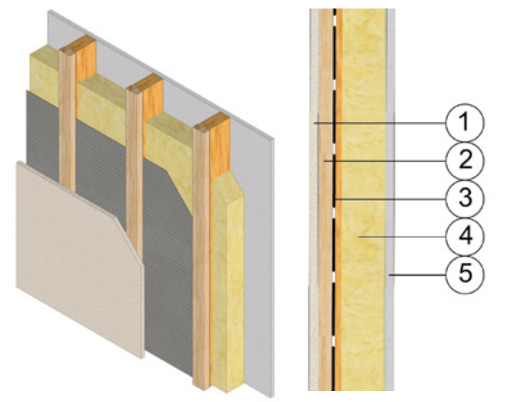
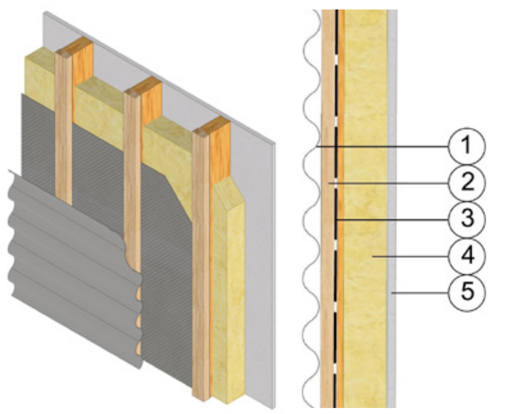
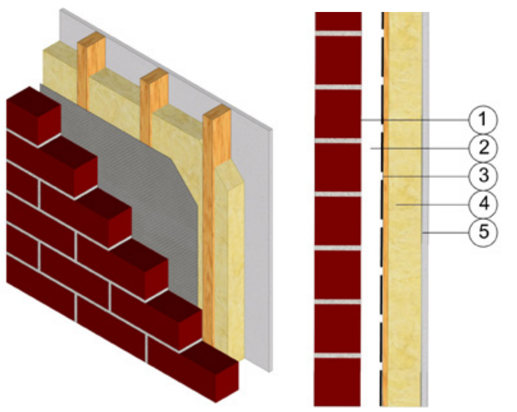
Cladding System	System Configuration			Acceptable Climate Zone
Housing or Non-fire Rated Exterior Wall				
Fibre Cement or Timber Cladding		1	8 mm fibre cement or timber cladding (profiled boards or panels)	**2, 5, 6 and 7**
		2	20 mm air space, slightly ventilated (8 ACH)	
		3	l.0 mm Class 4 pliable building membrane	
		4	Timber framing and 90 mm glasswool	
		5	10 mm plasterboard	
Sheet Metal Cladding		1	0.6 mm sheet metal cladding	**2, 5, 6 and 7**
		2	20 mm air space, slightly ventilated (8 ACH) and vertical battens	
		3	l.0 mm Class 4 pliable building membrane	
		4	Timber framing and 90 mm glasswool	
		5	10 mm plasterboard	
Brick Veneer		1	90 mm brick veneer	**2, 5, 6 and 7**
		2	25 mm cavity, slightly ventilated (8 ACH)	
		3	l.0 mm Class 4 pliable building membrane	
		4	Timber framing and 90 mm glasswool	
		5	10 mm plasterboard	

Table 2: Solution for Housing and Low-rise Buildings – Timber-Framing Cavity Construction (continued)

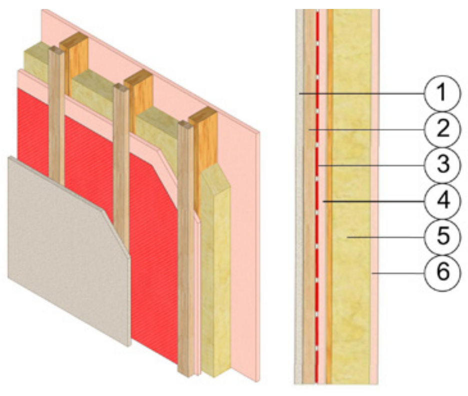
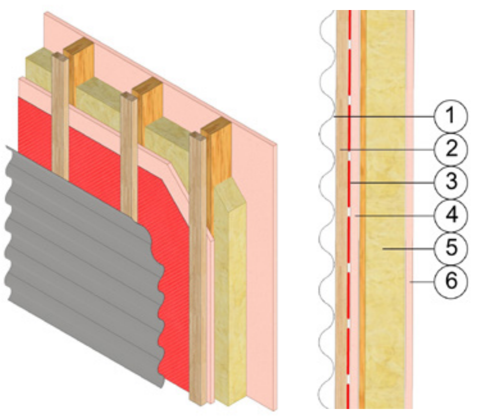
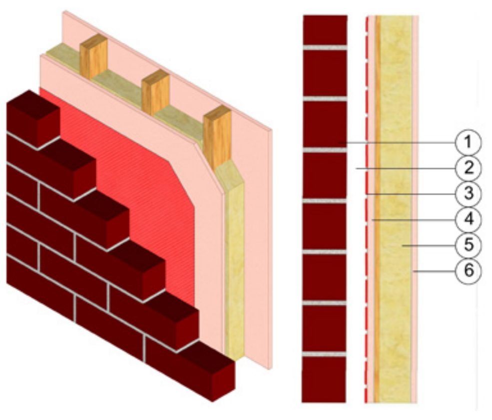
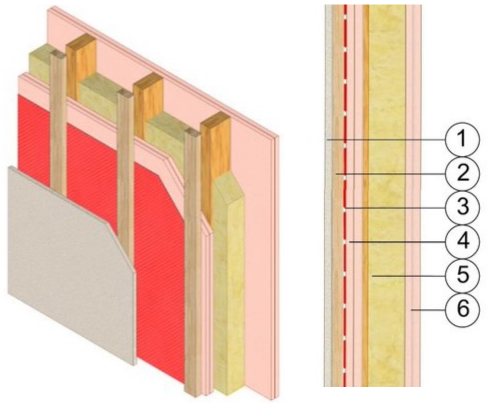
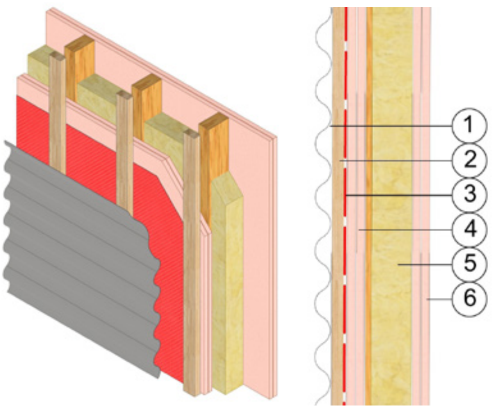
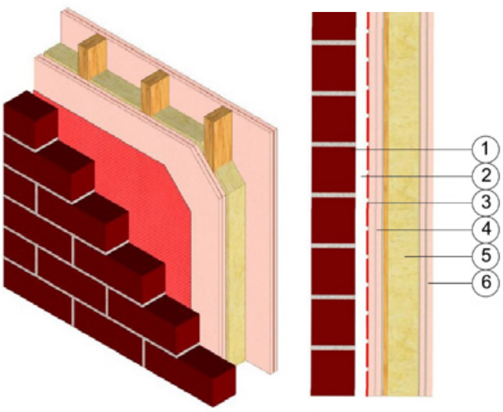
Cladding System	System Configuration			Acceptable Climate Zone
Low-rise Fire-Rated Exterior Wall (FRL 60)				
Fibre Cement or Timber Cladding		1	8 mm fibre cement or timber cladding (profiled boards or panels)	**2, 5, 6 and 7**
		2	20 mm air space, slightly ventilated (8 ACH) and vertical battens	
		3	l.0 mm Class 4 pliable building membrane	
		4	16 mm fire-protective plasterboard	
		5	Timber framing and 90 mm glasswool	
		6	10 mm plasterboard	
Sheet Metal Cladding		1	0.6 mm sheet metal cladding	**2, 5, 6 and 7**
		2	20 mm air space, slightly ventilated (8 ACH) and vertical battens	
		3	l.0 mm Class 4 pliable building membrane	
		4	16 mm fire-protective plasterboard	
		5	Timber framing and 90 mm glasswool	
		6	16 mm fire-protective plasterboard	
Brick Veneer		1	90 mm brick veneer	**2, 5, 6 and 7**
		2	20 mm air space, slightly ventilated (8 ACH)	
		3	l.0 mm Class 4 pliable building membrane	
		4	16 mm fire-protective plasterboard	
		5	Timber framing and 90 mm glasswool	
		6	16 mm fire-protective plasterboard	

Table 2: Solution for Housing and Low-rise Buildings – Timber-Framing Cavity Construction (continued)

Cladding System	System Configuration			Acceptable Climate Zone
Mid-Rise Fire-Rated Exterior Walls (FRL 90)				
Fibre Cement or Timber Cladding		1	8 mm fibre cement or timber cladding (profiled boards or panels)	**2, 5, 6 and 7**
		2	20 mm air space, slightly ventilated (8 ACH) and vertical battens	
		3	I.0 mm Class 4 pliable building membrane	
		4	2 x 13 mm fire-protective plasterboard	
		5	Timber framing and 90 mm glasswool	
		6	2 x 13mm fire-protective plasterboard	
Sheet Metal Cladding		1	0.6 mm sheet metal cladding	**2, 5, 6 and 7**
		2	20 mm air space, slightly ventilated (8 ACH)	
		3	I.0 mm Class 4 pliable building membrane	
		4	2 x 13 mm fire-protective plasterboard	
		5	Timber framing (90 mm)	
		6	2 x 13 mm fire-protective plasterboard	
Brick Veneer		1	90 mm brick veneer	**2, 5, 6 and 7**
		2	20 mm air space, slightly ventilated (8 ACH)	
		3	I.0 mm Class 4 pliable building membrane	
		4	2 x 13 mm fire-protective plasterboard1	
		5	Timber framing (90 mm)	
		6	2 x 13 mm fire-protective plasterboard	

Note: 1. The use of a 2 x 13 mm fire-protective plasterboard in this location may not be required as the masonry may provide the fire rating. The example is shown as a worse case, where the masonry does not provide fire protection.

Table 3: Solution for Housing and Low-rise Buildings – Timber-Framing Direct Fixed Construction

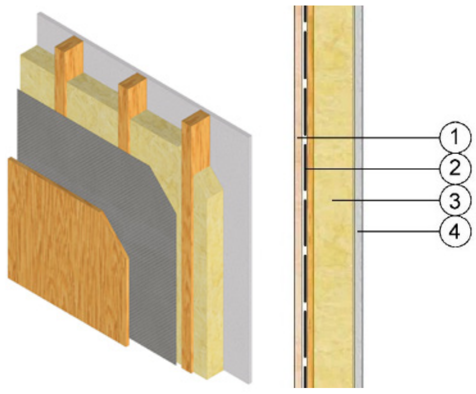
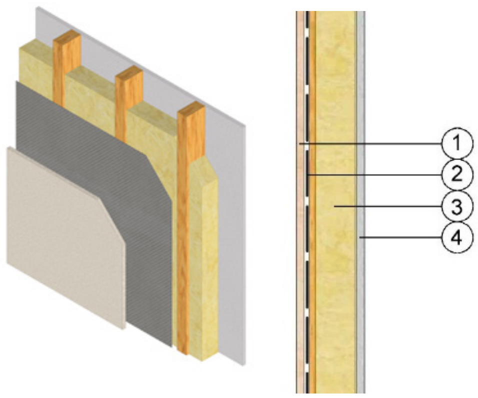
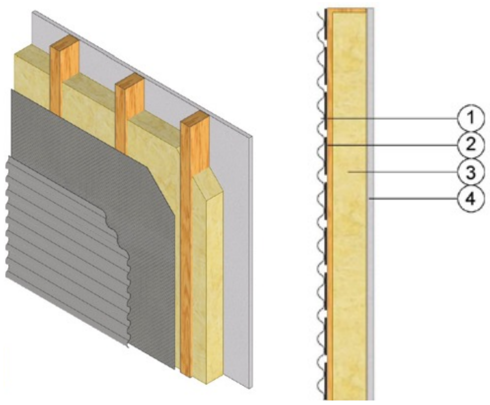
Cladding System	System Configuration			Acceptable Climate Zone
Housing or Non-fire Rated Exterior Wall				
Timber Cladding		1	Timber cladding (profiled boards or panels)	**2, 5, 6 and 7**
		2	I.0 mm Class 4 pliable building membrane	
		3	Timber framing and 90 mm glasswool	
		4	10 mm plasterboard	
Fibre Cement Cladding		1	8 mm fibre cement cladding	**2, 5 and 6**
		2	I.0 mm Class 4 pliable building membrane	
		3	Timber framing and 90 mm glasswool	
		4	10 mm plasterboard	
Metal Cladding		1	0.6 mm sheet metal cladding	**2**
		2	I.0 mm Class 4 pliable building membrane	
		3	Timber framing and 90 mm glasswool	
		4	10 mm plasterboard	

Table 3: Solution for Housing and Low-rise Buildings – Timber-Framing Direct Fixed Construction (continued)

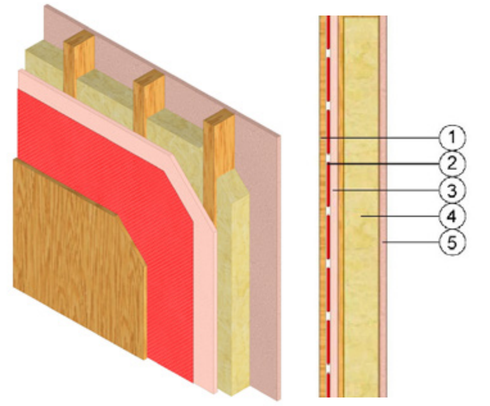
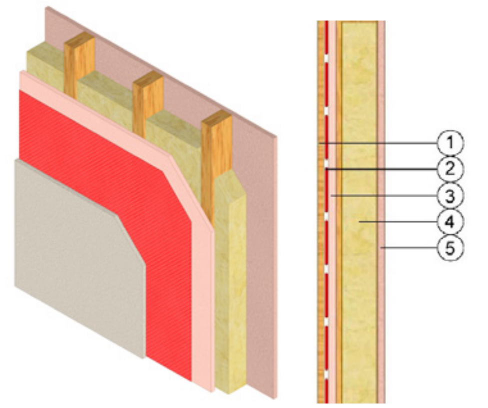
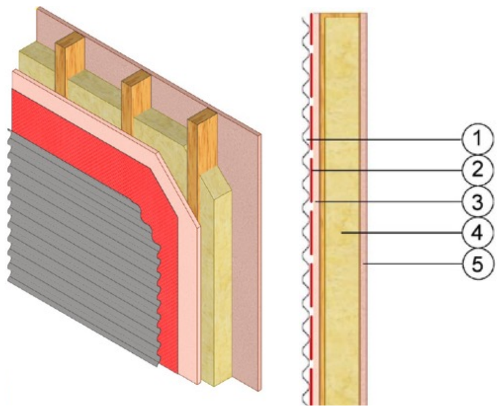
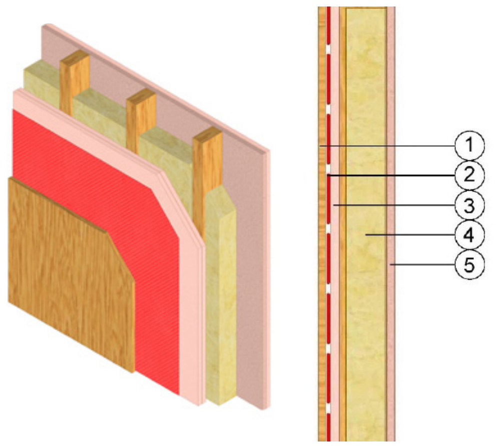
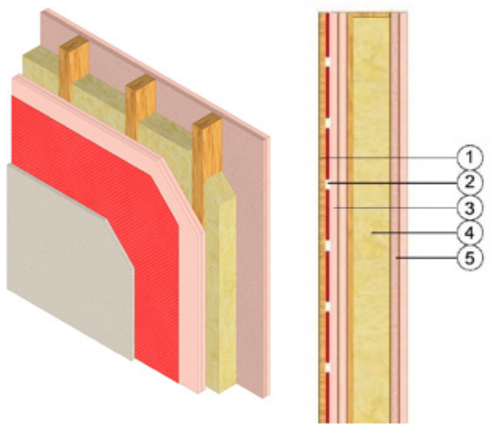
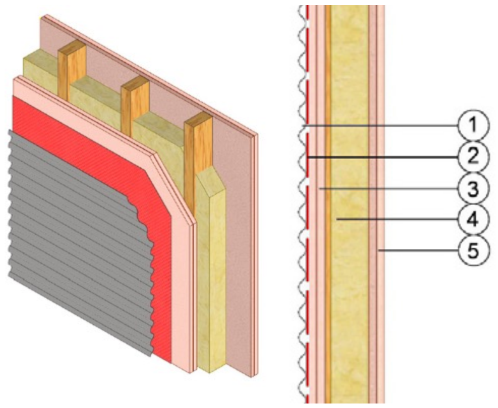
Cladding System	System Configuration			Acceptable Climate Zone
Low-rise Fire-Rated Exterior Wall (FRL 60)				
Timber Cladding		1	Timber cladding (profiled board or panels)	**2, 5, 6 and 7**
		2	I.0 mm Class 4 pliable building membrane	
		3	16 mm fire-protective plasterboard	
		4	Timber framing and 90 mm glasswool	
		5	16 mm plasterboard	
Fibre Cement Cladding		1	8 mm fibre cement cladding	**2, 5, 6 and 7**
		2	I.0 mm Class 4 pliable building membrane	
		3	16 mm fire-protective plasterboard	
		4	Timber framing and 90 mm glasswool	
		5	16 mm fire-protective plasterboard	
Sheet Metal Cladding		1	0.6 mm sheet metal cladding	**2 and 5**
		2	I.0 mm Class 4 pliable building membrane	
		3	16 mm fire-protective plasterboard	
		4	Timber framing and 90 mm glasswool	
		5	16 mm fire-protective plasterboard	

Table 3: Solution for Housing and Low-rise Buildings – Timber-Framing Direct Fixed Construction (continued)

Cladding System	System Configuration			Acceptable Climate Zone
Mid-Rise Fire-Rated Exterior Walls (FRL 90)				
Timber Cladding		1	Timber cladding (boards or panels)	**2, 5, 6 and 7**
		2	l.0 mm Class 4 pliable building membrane	
		3	2 x 13 mm fire-protective plasterboard	
		4	Timber framing and 90 mm glasswool	
		5	2 x 13 mm fire-protective plasterboard	
Fibre Cement Cladding		1	8 mm fibre cement cladding	**2, 5, 6 and 7**
		2	l.0 mm Class 4 pliable building membrane	
		3	2 x 13 mm fire-protective plasterboard	
		4	Timber framing and 90 mm glasswool	
		5	2 x 13 mm fire-protective plasterboard	
Sheet Metal Cladding		1	0.6 mm sheet metal cladding	**2 and 5**
		2	l.0 mm Class 4 pliable building membrane	
		3	2 x 13 mm fire-protective plasterboard	
		4	Timber framing and 90 mm glasswool	
		5	2 x 13 mm fire-protective plasterboard	

8.1.2.2 Roof Systems for Various Climate Zones

The following are various framed roof solutions for various climate zones. Where the ledger indicates the roof system is required to be ventilated, ventilation must be in accordance with NCC provision for ventilated roof cavity.

Table 4: Solution for Housing and Low-rise Buildings – Timber Frame

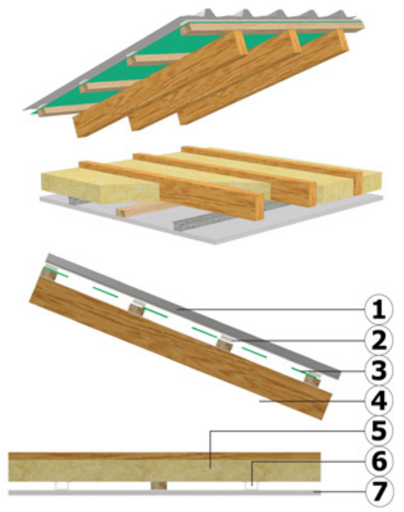
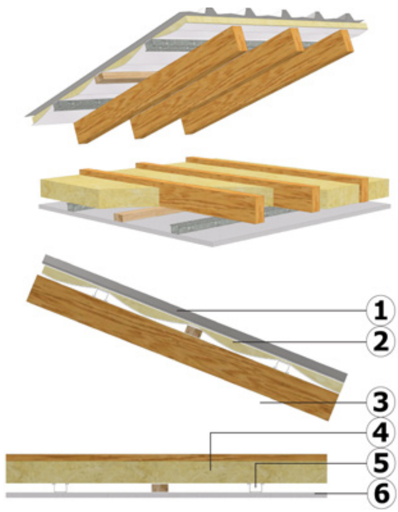
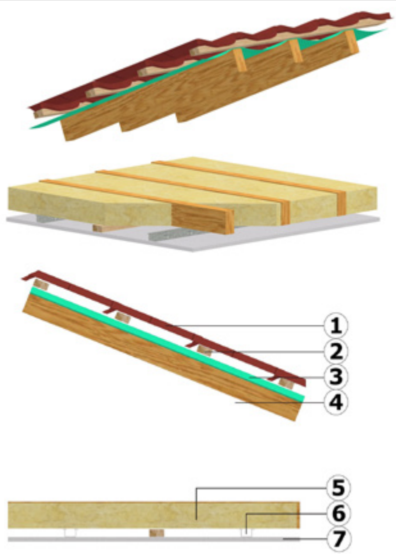
<table>
<tr><th>Cladding System</th><th colspan="3">System Configuration</th><th>Acceptable Climate Zone</th></tr>
<tr><td colspan="5">Pitched Roof (22⁰)</td></tr>
<tr><td rowspan="13">Sheet Metal Cladding</td><td rowspan="7">
</td><td>1</td><td>0.6 mm sheet metal cladding</td><td rowspan="7">2, 5, 6 and 7</td></tr>
<tr><td>2</td><td>25 mm air space, slightly ventilated and batten (35 ACH)</td></tr>
<tr><td>3</td><td>1.0 mm Class 4 pliable building membrane</td></tr>
<tr><td>4</td><td>Roof timber framing and ventilated cavity</td></tr>
<tr><td>5</td><td>165 mm insulation R3.2</td></tr>
<tr><td>6</td><td>Timber or metal ceiling battens, unventilated</td></tr>
<tr><td>7</td><td>10 mm plasterboard</td></tr>
<tr><td rowspan="6">
</td><td>1</td><td>0.6 mm sheet metal cladding</td><td rowspan="6">2, 5, 6 and 7</td></tr>
<tr><td>2</td><td>60 mm glasswool and reflective foil insulation</td></tr>
<tr><td>3</td><td>Roof framing and ventilated cavity</td></tr>
<tr><td>4</td><td>165 mm insulation R3.2</td></tr>
<tr><td>5</td><td>Timber or metal ceiling battens, unventilated</td></tr>
<tr><td>6</td><td>10 mm plasterboard</td></tr>
<tr><td rowspan="7">Tiled</td><td rowspan="7">
</td><td>1</td><td>Roof Tiles</td><td rowspan="7">2, 5, 6 and 7</td></tr>
<tr><td>2</td><td>25 mm air space, slightly ventilated and batten (35 ACH)</td></tr>
<tr><td>3</td><td>1.0 mm Class 4 pliable building membrane</td></tr>
<tr><td>4</td><td>Roof Timber framing and ventilated cavity</td></tr>
<tr><td>5</td><td>165 mm insulation R3.2</td></tr>
<tr><td>6</td><td>Timber or metal ceiling battens, unventilated</td></tr>
<tr><td>7</td><td>10 mm plasterboard</td></tr>
</table>

Table 4: Solution for Housing and Low-rise Buildings – Timber Frame (continued)

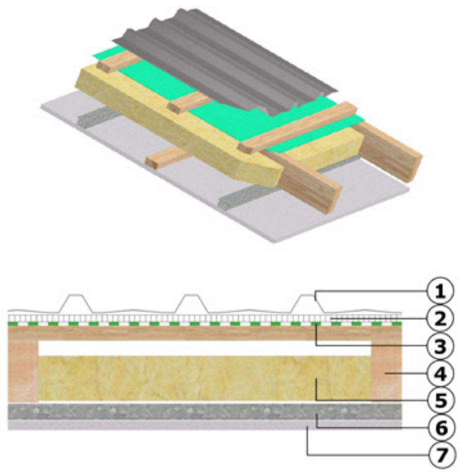
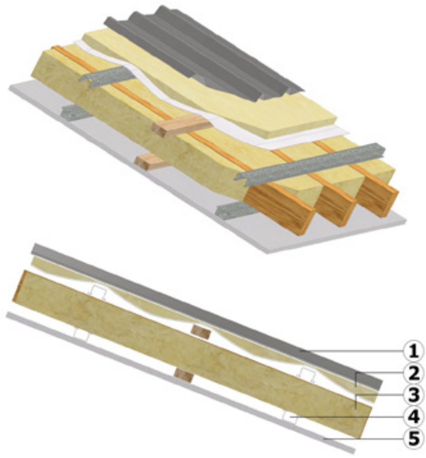
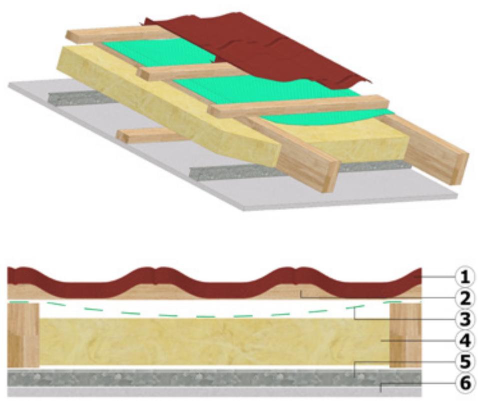
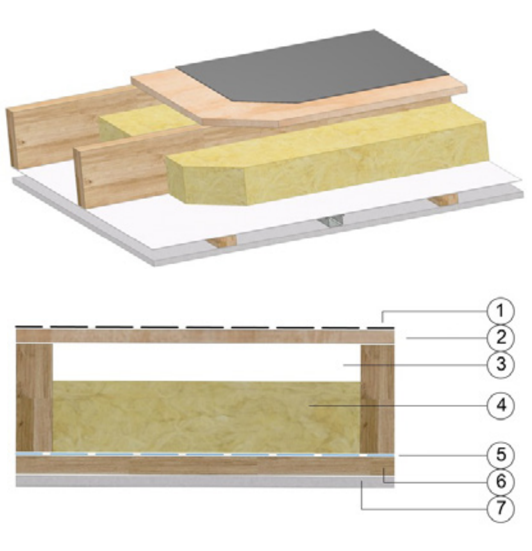
Cladding System	System Configuration			Acceptable Climate Zone
Cathedral Roof (22⁰)				
Sheet Metal Cladding		1	0.6 mm sheet metal Cladding	**2, 5, 6 and 7**
		2	25 mm air space, slightly ventilated and batten (35 ACH)	
		3	1.0 mm Class 4 pliable building membrane	
		4	Roof timber framing	
		5	165 mm insulation R3.2	
		6	Timber or metal ceiling battens, unventilated	
		7	10 mm plasterboard	
		1	0.6 mm Sheet Metal Cladding	**2, 5, 6 and 7**
		2	60mm glasswood face with vapour barrier	
		3	165mm insulation R3.2 with a minimum 20mm continuous ventilated air space (35 AHC) below the lowest point of vapour barrier backed insulation blanket.	
		4	Timber ceiling battens, unventilated	
		5	10 mm plasterboard	
Tiled		1	Tiles	**2, 5, 6 and 7**
		2	25 mm air space, slightly ventilated and batten (minimum 35 ACH)	
		3	1.0 mm Class 4 pliable building membrane	
		4	165 mm insulation R3.2	
		5	Timber ceiling battens	
		6	10 mm plasterboard	

Table 4: Solution for Housing and Low-rise Buildings – Timber Frame (continued)

Cladding System	System Configuration			Acceptable Climate Zone
Flat Roof				
Plywood and waterproof membrane		1	4 mm waterproof membrane	**2, 5, 6 and 7**
		2	18 mm plywood	
		3	Roof timber framing and cavity (minimum 35 ACH)	
		4	165 mm insulation R3.2	
		5	1 mm air vapour control layer	
		6	25 mm air space, slightly ventilated and batten	
		7	10 mm plasterboard	

8.1.3 Mass Timber

Mass timber varies from timber-frame options as the insulation can only be placed on either side of the mass timber element. Locating insulation to the exterior of the mass timber is the best approach, as this maintains the temperature of mass timber within a narrow band close to the interior temperature.

In a typical indoor environment maintained at 23°C and 50 per cent relative humidity, condensation can start to be observed on cold non-porous surfaces such as glass and aluminium at a temperature of 12°C or below. Condensation may not be visible on the surface of porous materials such as timber or plasterboard at the same temperature. However, rather than visible surface condensation being observed, the moisture content of porous materials will rise.

Figure 28 shows a wall system with interior insulation. The temperature at the interface between the insulation and the mass timber falls as low as 7°C, which is well below Dew Point temperature, causing the moisture content of the mass timber to rise, that may promote mould and degradation of the timber.

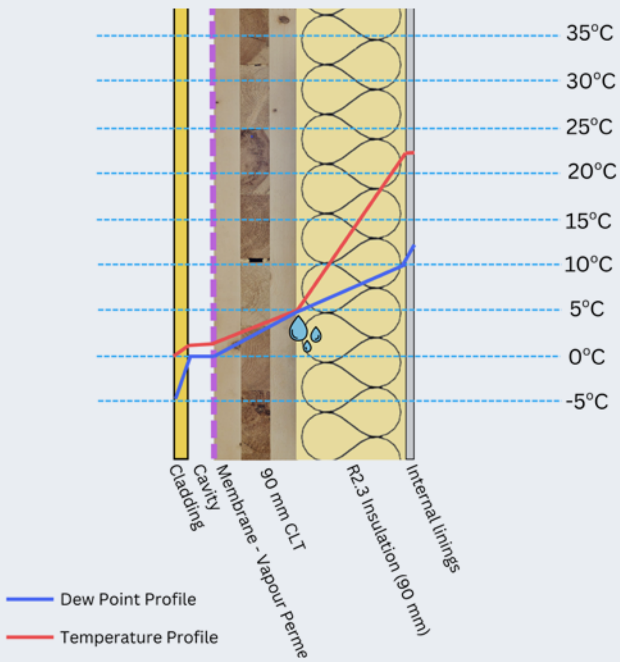


Figure 28: Dew Point Temperature reached during winter with interior insulation (Image credit: TDA)

Where exterior insulation is used, as shown in Figure 29, the temperature of the mass timber stays above 16°C, well above the Dew Point temperature, resulting in no condensation occurring on or near the mass timber.

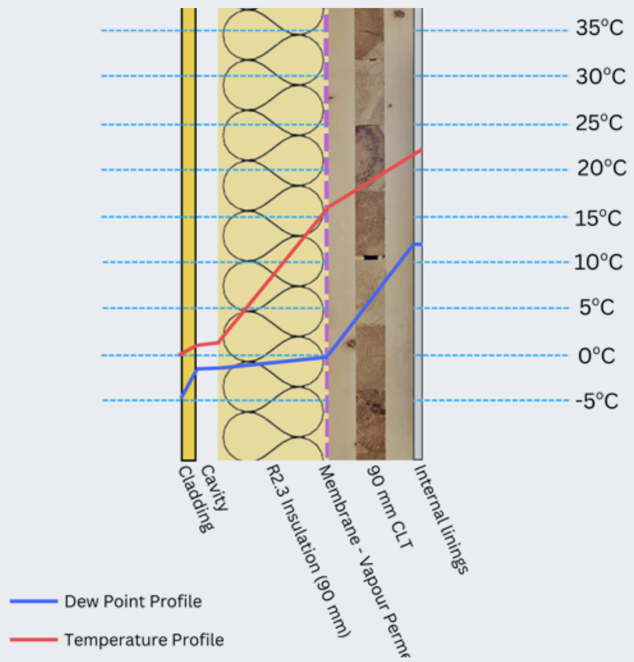


Figure 29: Temperature of timber maintained above Dew Point Temperature in winter with exterior insulation (Image credit: TDA).

Note: Where water-sensitive insulation such as glasswool (as opposed to hydrophobic stonewool) is used, an additional pliable building membrane is required on the exterior side of the insulation.

The placement of sufficient insulation on the exterior of the mass timber plays a crucial role in keeping the timber above the Dew Point in the winter for cool and temperate climates. In summer, refer to Figure 30, the positioning of insulation is less crucial from a condensation perspective. However, external insulation does keep the mass timber closer to the interior temperature.

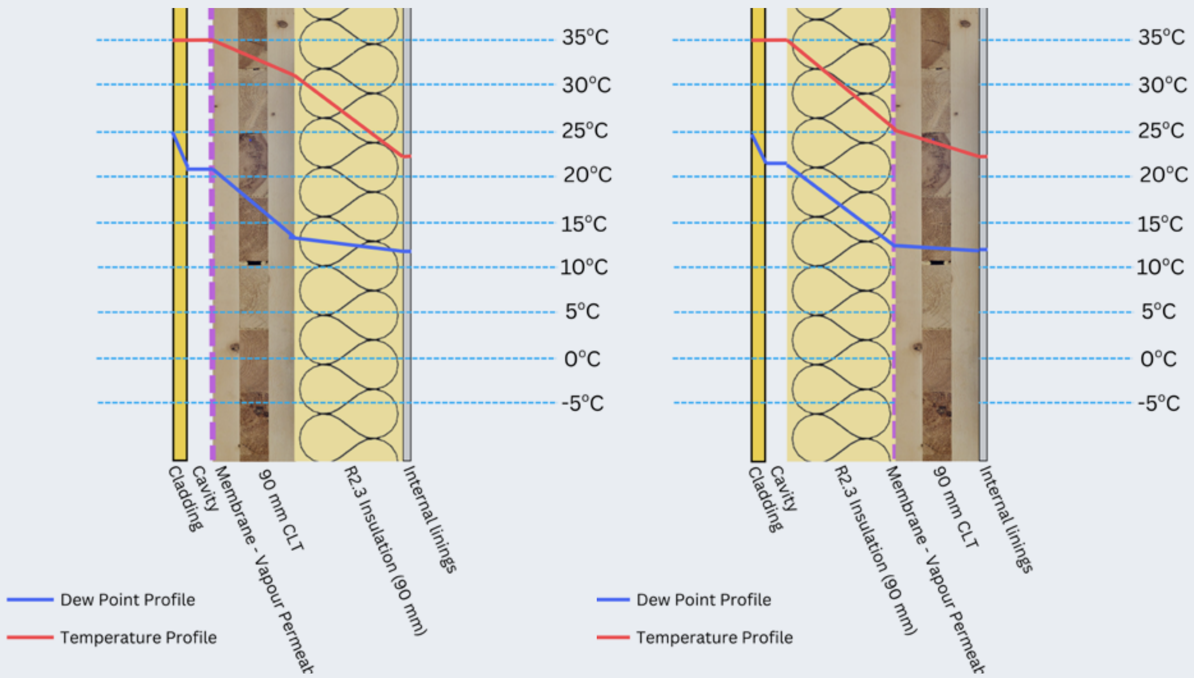


Figure 30: Temperature and dew point profiles in the summer for interior and exterior insulation (Image credit: TDA).

In hot and humid tropical climates, the critical consideration for buildings that are cooled are:

1 That the construction is airtight such that the uncontrolled infiltration of hot, humid air from the exterior to the interior is minimised

2 That there are no vapour impermeable layers to the interior side of the insulation, including internal linings, where they could be cooled to the Dew point temperature of outside air.

Due to the particular demands condensation has in tropical climates, it is beyond the scope of this guide to include specific details. It is suggested that a mechanical engineer with experience be consulted to ensure that the building envelope and HVAC design are appropriate for these locations. Excellent guidance is available in the AIRAH application manual DA20[11].

8.1.3.1 Placement of vapour impermeable materials in the building envelope

Exterior claddings such as metal, glass and some stone claddings are impermeable, and thus vapour cannot pass through these materials. If the cladding is at or below the Dew Point temperature, condensation may form on the surface of such materials. This issue is not necessarily a problem if the materials are located adjacent to a cavity where the condensate can be ventilated or safely drained away without collecting on or within moisture-sensitive materials.

The correct selection and the positioning of pliable membranes within the building envelope are essential to managing condensation. The type of insulation is also important; however, it is primarily determined by the regulatory requirements with respect to combustibility for various types of construction and building height. For clarity, the following sections consider these products separately.

a) NCC's Type A and B construction – Class 2 to 9. Exterior walls in this application must be built using non-combustible materials, except structural timber can be used if it meets the NCC's Fire-Protected timber requirements or concession for low-rise residential construction. Refer to the section of the guide on fire resistance of external walls for more information. In addition, a pliable building membrane is required to be less than 1 mm thick with a flammability index no greater than 5. Any insulation material used within the exterior wall needs to be non-combustible, i.e. tested in accordance with AS 1530.1[12.] There are no limits on the combustibility of the insulation used for roofs.

b) NCC's Class 1 and 10 and Type C construction Class 1 to 9: There are no specific limits on the combustibility of elements within this construction category. However, in some situations, they do need to meet specific fire hazard properties; refer to Section 10 of this guide.

8.1.3.2 Type A and B construction – Class 2 to 9 Solution

The following is the suggested construction to minimise condensation issues: refer to Figure 31. Where the insulation is not stonewool, a vapour-permeable pliable membrane is required on the exterior side of the insulation.

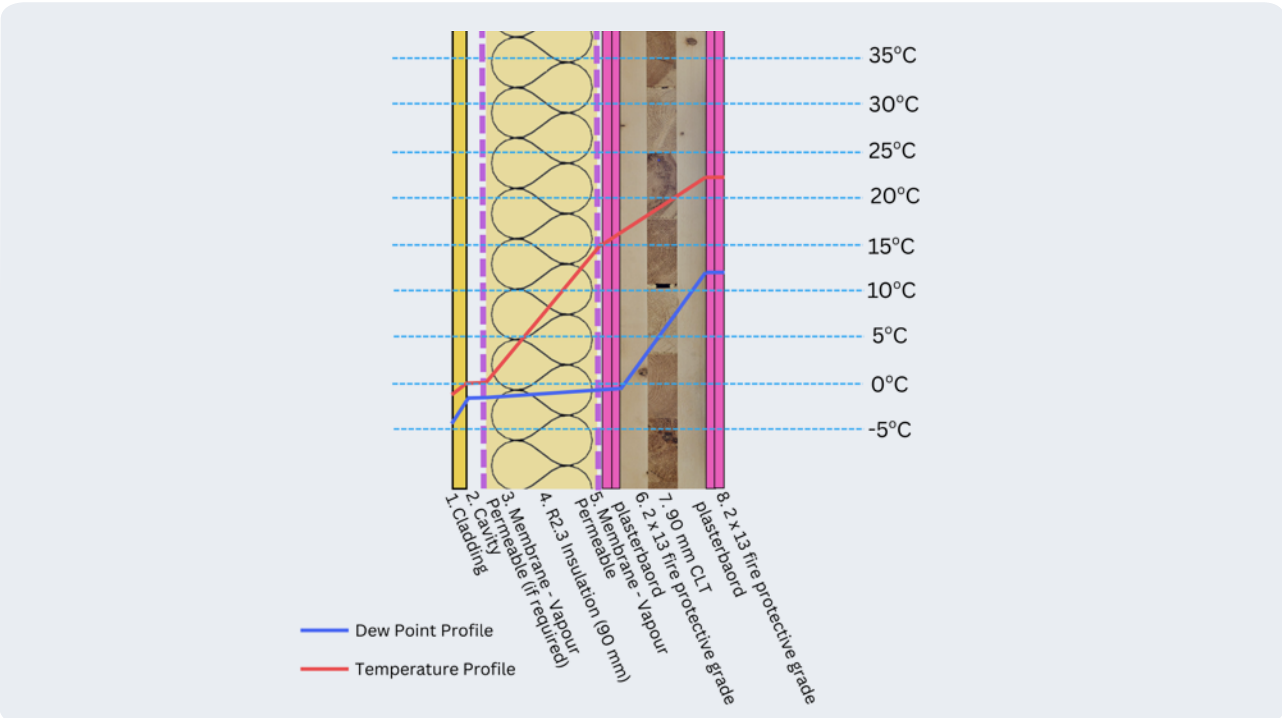


Figure 31: Suggested option for non-combustible construction (Image credit: TDA)

Cladding [Item 1]

The cladding must be any non-combustible system. Where the cladding is weather-resistant, it is defined by the NCC as the water control layer. However, if the cladding is not weather resistant, it is considered a rain screen. It requires a weatherproof layer to be installed, generally on the surface of a moisture sensitive insulation.

Cavity [Item 2]

The primary consideration is to ensure that the pliable building membrane or insulation does not create a capillary bridge across the cavity. Typically, the minimum dimension of the cavity of 20 mm, which should achieve this. However, a masonry system requires a 25 mm cavity to comply with the NCC. The thickness of non-combustible mineral fibre insulation is generally a minimum of 75 mm. Non-combustible rain screen façade support systems are ideal as these can often accommodate insulation up to 300 mm, reduce thermal bridging and offer an engineered solution to support a wide range of claddings. Also, the cavity must be ventilated so that outdoor air can pass through the cavity to allow for drying.

Pliable building membrane [Items 3]

A pliable building membrane is required where the exterior cladding is not considered a water control layer or where water-sensitive insulation, such as glasswool, is used. A pliable building vapour permeable membrane should be used as a water barrier in these cases.

On the other hand, where stonewool insulation is used, it can be used behind a rain screen unfaced by a water-resistive membrane. This is due to stone wool being hydrophobic (repels or fails to mix with water). However, the timber must be protected by a water-resistive vapour permeable membrane, as discussed in Item 5.

Insulation [Item 4]

Insulation type is generally determined by the external wall's energy efficiency and fire resistance requirements. For either Type A or B building classification, the insulation has to be non-combustible, or if it is a multi-layer product, it must comply with the NCC Provision. Most non-combustible insulation products are generally limited to mineral fibre materials, i.e. glasswool or stonewool. Mineral fibre insulation is porous, vapour, and air permeable but must be kept dry. Water penetrating the exterior cladding can pass through the mineral fibre insulation, so the timber needs to be protected by a water-resistive vapour permeable membrane.

If a facing is bonded to the insulation, this layer needs to be vapour permeable and non-combustible to comply with the NCC's requirements as a bonded laminate. Where stonewool insulation is used behind an exterior cladding, it can potentially be used without a membrane for protection against saturation and wind washing.

Pliable building membrane [Items 5]

The pliable building membrane should be a water and air barrier and vapour permeable. The performance characteristics are tested and reported as per AS/NZS 4200.1[7]; see below for a discussion on the performance characteristics of pliable building membranes.

At this point, it is essential to minimise thermal bridging through the exterior cladding framing support system to minimise this risk of localised areas of timber being at or below the dew point temperature. Where high-performance thermal breaks are used in the sub-framing in external walls, they must also be non-combustible, generally not possible with readily available systems.

Fire protective covering [Item 6]

The requirements for the fire protective covering are explained in detail in Section C Provision C2D13 of the NCC Volume 1, and further information is available from Wood Solution Guide No 37 R[13] and C[13]. The fire protective covering should preferably be vapour permeable.

Depending on the application, the fire-protective covering is typically two layers of 13 mm of fire-protective grade plasterboard; however, other non-combustible materials that meet the NCC Volume 1 Provision C2D10 could be considered.

The NCC fire-protected fire resistance systems require cavity barriers. The addition of cavity barriers may interfere with ventilated cavities. Refer to the section within this guide regarding conflicts with NCC provisions.

8.1.3.3 Class 1 and 10 and Type C construction Class 1 to 9 Solution

External walls in Class 1 and 10 buildings or Type C Class 1 to 9 buildings are not required to be non-combustible. However, there are fire hazard properties to be met. External walls for these building applications also do not need to have a fire-protected timber compliance system. Therefore, including fire-protective plasterboard is optional for mass timber, i.e. the mass timber can provide fire resistance by itself. The following is the suggested construction to minimise condensation issues: refer to Figure 32.

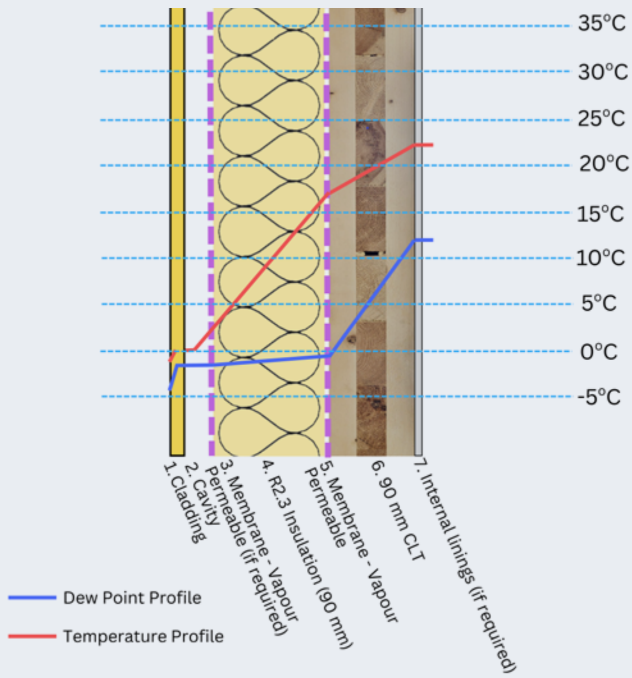


Figure 32: Suggested option where non-combustible construction is not required (Image credit: TDA)

Cladding [Item 1]
The cladding can be any combustible or non-combustible system. Where the cladding is weather-resistant, it is defined by the NCC as the water control layer. However, if the cladding is not weather resistant, it is considered a rain screen. It requires a weatherproof layer to be installed, generally on the surface of the water susceptible insulation.

Cavity [Item 2]
The primary consideration is to ensure that the pliable building membrane or insulation does not create a capillary bridge across the cavity. Typically, the minimum dimension of the cavity of 20 mm, which should achieve this. However, a masonry system requires a 25 mm cavity to comply with the NCC. The thickness of non-combustible mineral fibre insulation is generally a minimum of 75 mm. Non-combustible rain screen façade support systems are ideal as these can often accommodate insulation up to 300 mm, reduce thermal bridging and offer an engineered solution to support a wide range of claddings. Also, the cavity must be ventilated so that outdoor air can pass through the cavity to allow for drying.

Pliable building membrane [Items 3]
A pliable building membrane is required where the exterior cladding is not considered a water control layer or where water-sensitive insulation, such as glasswool, is used. A pliable building vapour permeable membrane should be used as a water barrier in these cases.

On the other hand, where stonewool insulation is used, it can be used behind a rain screen unfaced by a water-resistive membrane. This is due to stone wool being hydrophobic (repels or fails to mix with water). However, the timber must be protected by a water-resistive vapour permeable membrane, as discussed in Item 5.

Insulation [Item 4]
Types of insulation are not limited to Class 1 and 10 building applications, but fire hazard property limits apply for Type C Class 2 to 9, i.e. NCC Specification C1.10.

Polyisocyanurate insulation (PIR) is thermoset insulation that can offer a good R-value in thin, moisture-resistant, dimensionally stable closed-cell boards. Although some thermoplastic insulation materials such as extruded (XPS) and expanded (EPS) polystyrene may comply, thermoset insulation such as PIR is preferable in rain screen construction for reasons of fire performance. Mineral fibre insulation can also be used. However, Polyisocyanurate (PIR), extruded (XPS) and expanded (EPS) polystyrene insulation is not vapour permeable. Their use is dependent on the assumption that they keep the mass timber above the Dew point temperature and that the interior of the building is ventilated by other means, i.e. not dependent on vapour transmission through the exterior wall. An indication of the minimum level of insulation performance required is given in Table 5 systems that have been verified to comply with the NCC.

Pliable building membrane [Items 5]
The pliable building membrane should be a water and air barrier and vapour permeable. The performance characteristics are tested and reported as per AS/NZS 4200.1[7]; see below for a discussion on the performance characteristics of pliable building membranes.

At this point, it is even more crucial to avoid thermal bridging through the cladding support system and for there to be sufficient insulation to keep the pliable building membrane at a temperature above Dew Point.

8.1.3.4 Discussion on Recommendation made on Materials Selection

Why is it preferable to have the pliable building membrane on the outside face of the fire-protected mass timber vapour-permeable, i.e. non-combustible exterior wall?
With the insulation keeping the mass timber above the Dew Point, a compliant vapour barrier material could work as effective water and air barrier. With sufficient insulation and no thermal bridging, the pliable building membrane could be maintained above the dew point in winter in cold and temperate climates. However, the use of a vapour-permeable pliable building membrane, in addition to providing effective water and air control, also provides for drying potential toward the exterior from the mass timber during construction and for the life of the building in the event of water ingress.

Why do we need two layers of pliable building membrane?
Not always. The pliable building membrane on the face of the fire-protected mass timber is required to protect the structure from water ingress. Where the exterior cladding is not considered to be a water control layer, i.e. in rain screen construction, a pliable building membrane must be placed on the outer face of glasswool insulation to protect from water ingress.

Where the insulation is faced with a vapour-permeable membrane that is detailed and installed continuously and sealed to protect both the insulation and the structure, in this case, this could negate the need for an additional pliable building membrane layer on the face of the fire-protected mass timber. This situation is more likely to be achieved with controlled off-site installation and an engineered façade support system. Where this does not occur, installing a pliable building membrane directly to the mass timber or fire protective linings is recommended.

What performance does the pliable building membrane need to achieve?
The performance characteristics of pliable building membranes are tested and reported as per AS/NZS 4200.1[7]. They must also pass AS 4201.4 Resistance to water penetration test[15] and be a Class 4 in accordance with AS/NZS 4200.1[7] Table 4 Vapour Control Membrane Classification, i.e., minimum vapour permeance of 1.14 µg/N.s equivalent to the inverse - maximum vapour resistance of 0.88 MN.s/g, as this is the assumption used in the modelling.

The pliable building membrane used in NCC's Class 2 to 9 buildings also has fire hazard properties to meet. Generally, the pliable building membrane must not exceed 1 mm in thickness and have a Flammability Index not greater than 5, discussed in more detail in this guide's fire-resistance external wall section.

In summary, a pliable building membrane should comply with AS/NZS 4200.1[7] and should be a least, if not more, permeable than the internal layer of wall lining.

- Water Barrier: High
- Vapour permeance > 1.142 g/N.s Class 4 (resistance < 0.88 MN.s/g)
- Air barrier: Air resistance of ≥ 0.1 MNs/m³
- Comply with the NCC Material Fire Properties

  Volume One:

  Wall:

  - Required to be Non-combustible – Provision C2D10 Non-Combustible, sarking type material – not exceeding 1 mm thickness and have a Flammability Index not greater than 5
  - No non-combustibility requirement – Provision C2D11 Fire Hazard Property, Specification 7, Fire Hazard Property, S7C7, Other Materials - flammability Index not greater than 5

  Roof:

  Provision C2D11 Fire Hazard Property Specification 7, Fire Hazard Property, S7C7 Other Materials - flammability Index not greater than 5

  Volume Two:

  Roof:

  Specification 3, and DTS Provision H3D2 – Flammability Index not greater than 5

What about Cavity Barriers?
The NCC DTS fire-protected timber requirement requires cavity barriers as part of the fire-protected timber construction solution. The detail requires the cavity to be blocked at various locations, as specified in NCC Volume One, Specification 9. Where this occurs, the detailing of the cavity barrier should ensure drainage to the outside occurs at each floor level.

Ventilated cavity barrier may offer a solution for a fully vented façade; refer to Figure 33. However, it would need to be considered as part of a performance solution, as ventilated cavity barriers don't meet the NCC requirement for a cavity barrier.

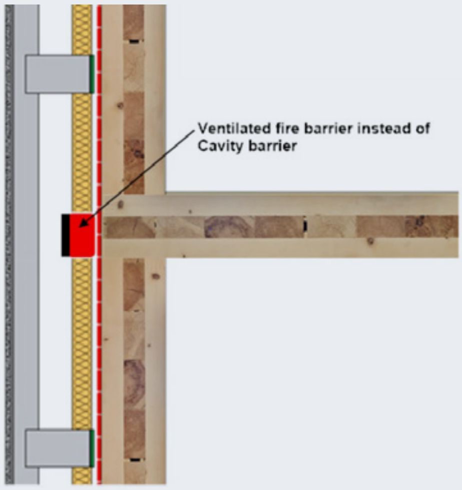


Figure 33: Ventilated Cavity Barrier (Image credit TDA)

Is a cavity required between the insulation and the vapour permeable membrane?

When porous insulation such as mineral fibre is used, a cavity is not required as vapour will diffuse through it, and any moisture that finds its way into the insulation will drain within the porous insulation. However, where a rain-screen is used, i.e. the cladding is not considered the water control layer, the cavity in conjunction with either the vapour permeable pliable building membrane or the sealed face of the insulation should be detailed to provide a barrier to moisture ingress.

There are situations where a drained and unventilated cavity is required between the insulation and the vapour-permeable pliable building membrane. However, this is beyond the scope of this guide, and no verified modelled solution is provided. Where there is no cavity, and a secondary barrier to moisture ingress exterior to the insulation is not possible, the insulation, in this case, should be closed cell and able to resist the level of moisture ingress expected.

Furthermore, where there is no drained or vented cavity behind a rain screen cladding, such as rendered exterior rigid insulation boards, a cavity between the insulation and the timber is recommended to provide a pathway for the moisture to escape. A cavity is required in this situation, as moisture may enter from alternative sources, such as poor window detailing or leaks over the life of the building. It is also required where the insulation external to the mass timber is insufficient to keep the inner face of the insulation board above the Dew point temperature, and condensation is anticipated. In this situation, the moisture must be effectively drained.

Moreover, when including a cavity between the insulation and the vapour-permeable pliable building membrane, it is crucial that this is not ventilated, as this would devalue the value of the insulation layer. It is essential that the cavity is closed and does not permit outside air circulation into the cavity but still permits drainage of any trapped moisture.

8.1.3.5 Airtightness and Ventilation

The ventilation approach will have an impact on interior humidity. Higher levels of absolute humidity increase the risks of condensation. However, when compared to other materials, mass timber has an inherent advantage as mass timber can safely store and release limited amounts of moisture. This take-up or release of moisture can assist in regulating comfortable indoor humidity levels within the building.

Commentary: The tendency of hygroscopic materials such as timber to take up water vapour as relative humidity rises can moderate conditions by temporarily storing water vapour and releasing it later when drying conditions prevail. Therefore products like mass timber and likely to effect the relative humidity of the indoor environment, in a positive way.

If a natural ventilation pathway to compliance is adopted, it is often primarily reliant on occupants opening windows periodically throughout the day to induce air exchange. However, recent experience in Australia indicates that occupants cannot be relied upon to regularly open windows, particularly in winter, at night, and during the day when homes remain unoccupied

General guidance suggests, as a minimum, that a residential building has around 6 to 8 air changes per hour (ACH) at 50 Pa. When the ventilation rate is below this, the ventilation should be assisted by continuous mechanical ventilation. Options include heat recovery ventilation, balanced supply and exhaust ventilation or continuous low-volume exhaust ventilation with passive trickle ventilation.

Furthermore, mass timber building envelopes should be of sufficient airtightness that infiltration should not be relied upon to provide makeup air; in this case, the Australian Standard AS 1668.2[18] requires the provision for makeup air to be provided.

8.1.3.6 Mass Timber Wall Solution for Various Climate Zones

Table 5 describes various mass timber wall and roof systems and the Climate Zones they are recommended to be used. Refer to Appendix A for more information on the modelling conducted to achieve this recommendation and the assumptions used.

Where additional plasterboard or difference thickness is required within the system for increased fire resistance, the addition of the plasterboard will not be detrimental to the system's performance.

Table 5: Solution for Housing and Low-rise Buildings – Mass Timber

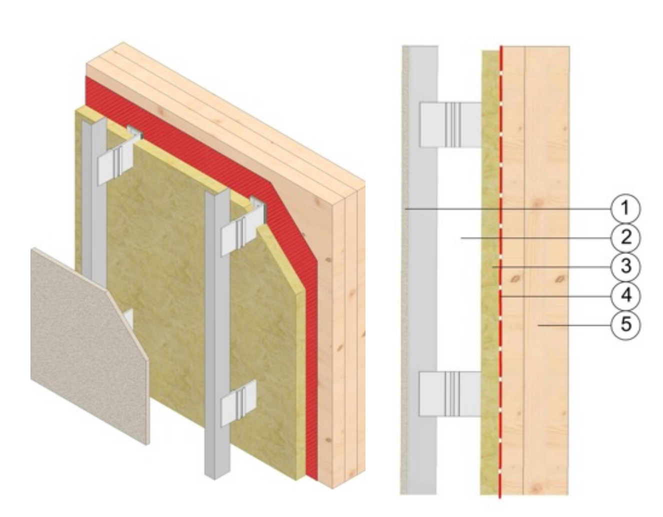
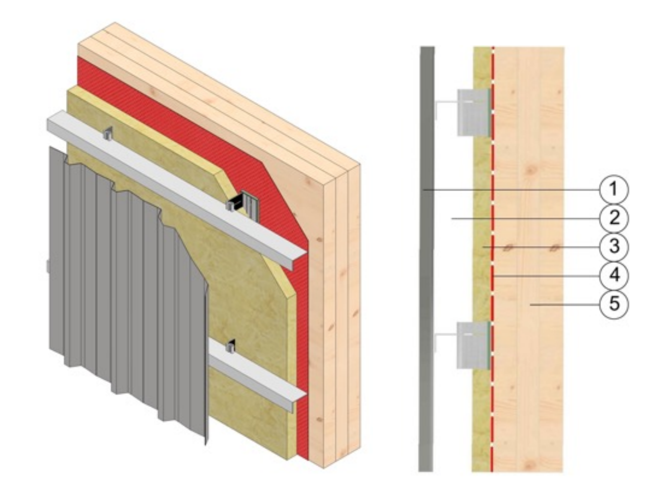
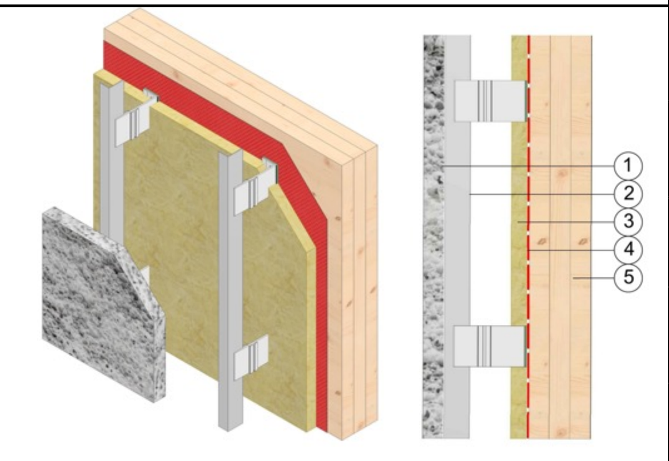
Cladding System	System Configuration			Acceptable Climate Zone
Housing and Low-rise Buildings *Note: Not intended to comply with the NCC's Fire-protected Timber Concession*				
Fibre Cement or Timber Cladding		1	8 mm fibre cement or timber cladding	**2, 5, 6 and 7**
		2	20 mm air space, slightly ventilated at (8 ACH)	
		3	60 mm stonewool R1.76	
		4	I.0 mm Class 4 pliable building membrane	
		5	90 mm CLT	
Sheet Metal Cladding		1	0.6 mm Sheet Metal Cladding	**2, 5, 6 and 7**
		2	20 mm air space, slightly ventilated at (8 ACH)	
		3	60 mm stonewool R1.76	
		4	I.0 mm Class 4 pliable building membrane	
		5	90 mm CLT	
Autoclaved Aerated Concrete		1	50 mm Autoclaved aerated concrete	**2, 5, 6 and 7**
		2	25 mm air space, slightly ventilated at (8 ACH)	
		3	60 mm stonewool	
		4	I.0 mm Class 4 pliable building membrane	
		5	90 mm CLT	

Table 5: Solution for Housing and Low-rise Buildings – Mass Timber (continued)

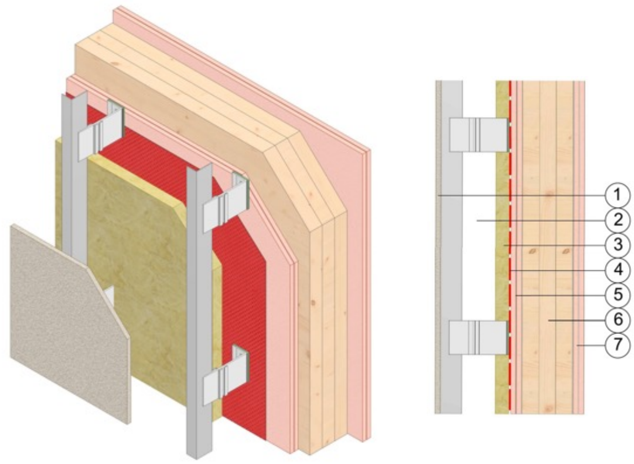
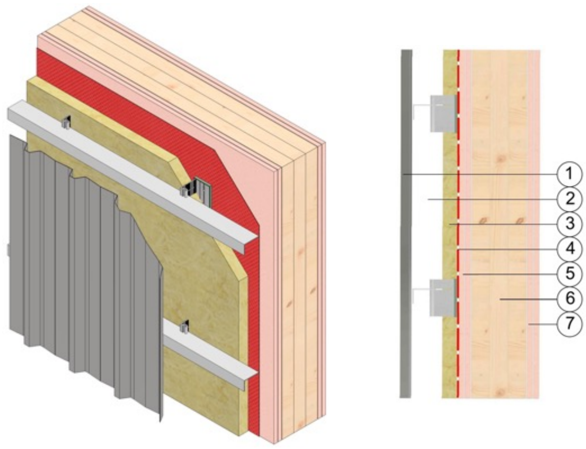
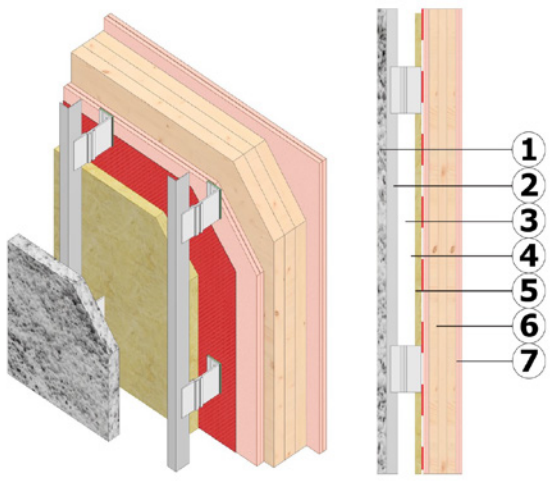
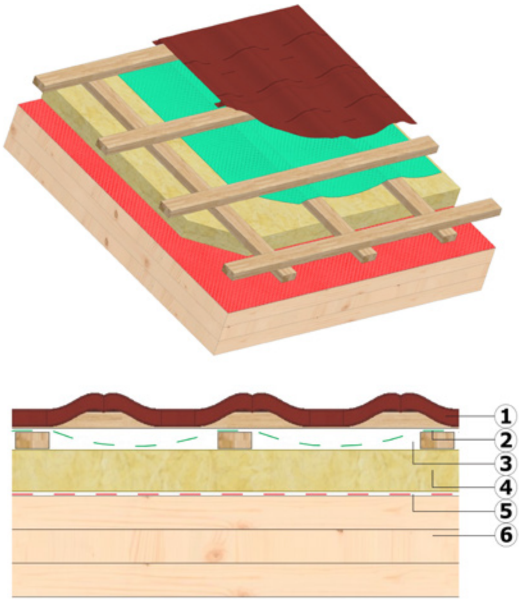
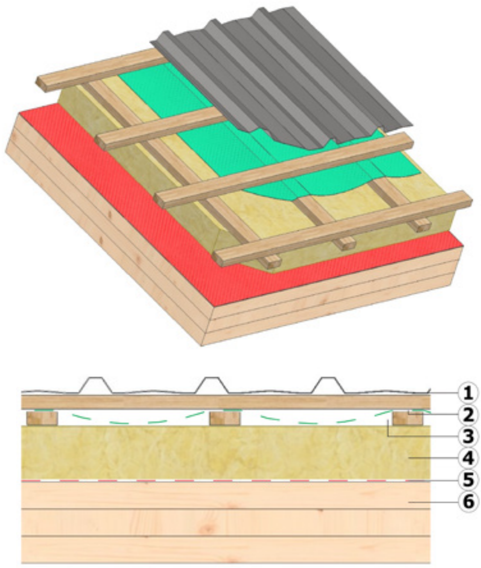
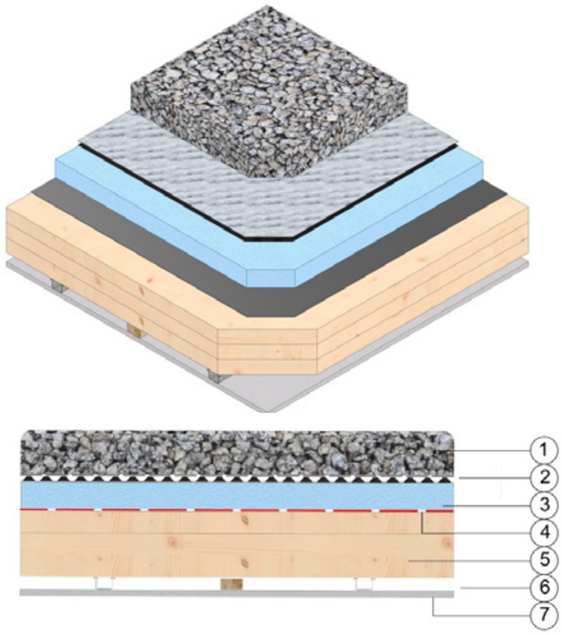
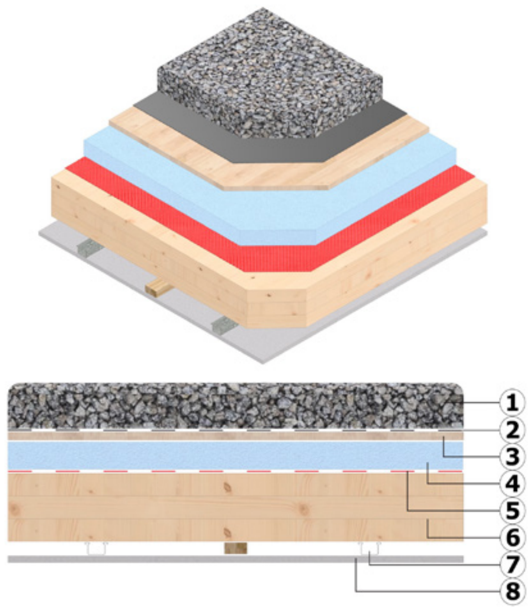
Cladding System	System Configuration			Acceptable Climate Zone
Mid-Rise Exterior Walls intending to comply with the NCC's Fire-protected Timber Concession				
Fibre Cement or Timber		1	8 mm fibre cement or timber cladding	**2, 5, 6 and 7**
			20 mm air space, slightly ventilated at (8 ACH)	
		3	60 mm stonewool R1.76	
		4	I.0 mm Class 4 pliable building membrane	
		5	2 x 13 mm fire-protective plasterboard	
		6	90 mm CLT	
		7	2 x 13 mm fire-protective plasterboard	
Sheet Metal Cladding		1	0.6 mm Sheet Metal Cladding	**2, 5, 6 and 7**
		2	20 mm air space, slightly ventilated at (8 ACH)	
		3	60 mm stonewool R1.76	
		4	I.0 mm Class 4 pliable building membrane	
		5	2 x 13 mm fire-protective plasterboard	
		6	90 mm CLT	
		7	2 x 13 mm fire-protective plasterboard	
Autoclaved Aerated Concrete		1	50 mm Autoclaved aerated concrete	**2, 5, 6 and 7**
		2	25 mm air space, slightly ventilated at (8 ACH)	
		3	60 mm stonewool	
		4	I.0 mm Class 4 pliable building membrane	
		5	2 x 13 mm fire-protective plasterboard	
		6	90 mm CLT	
		7	2 x 13 mm fire-protective plasterboard	

Table 6: Solution for Housing and Low-rise Buildings – Mass Timber.

Cladding and Roof Configuration	System Configuration			Acceptable Climate Zone
Cathedral Roof (22°)				
Tiled		1	Roof Tiles	**2, 5, 6 and 7**
		2	25 mm air space and batten (35 ACH)	
		3	1.0 mm Class 4 pliable building membrane	
		4	100 mm Stonewool R2.9	
		5	1.0 mm Class 4 pliable building membrane	
		6	120 mm CLT	
Metal Clad		1	Metal Cladding	**2, 5, 6 and 7**
		2	25 mm air space and batten (35 ACH)	
		3	1.0 mm Class 4 pliable building membrane	
		4	100 mm Stonewool R2.9	
		5	1.0 mm Class 4 pliable building membrane	
		6	120 mm CLT	

8.1.3.7 Mass Timber Roof Solution for Various Climate Zones

Table 6: Solution for Housing and Low-rise Buildings – Mass Timber (continued).

Cladding and Roof Configuration	System Configuration			Acceptable Climate Zone
Flat Roof				
Inverted Roof Membrane Assembly (to minimum fall)		1	Optional 50 mm gravel or pavers	**2, 5, 6 and 7**
		2	1.0 mm Class 4 pliable building membrane	
		3	75 mm XPS insulation	
		4	3.0 mm Waterproof membrane	
		5	120 mm CLT	
		6	Ceiling Battens, unventilated	
		7	10 mm plasterboard	
Warm roof (to minimum fall)		1	Optional 50 mm gravel or pavers	**2, 5, 6 and 7**
		2	3.0 mm Waterproof membrane	
		3	Wood panel H3 preservative treated	
		4	75 mm XPS insulation	
		5	Vapour barrier	
		6	120 mm CLT	
		7	Ceiling battens unventilated	
		8	10 mm plasterboard	

9 Junctions between Roof and External Wall

When superior wall and roof insulation and condensation configuration are often installed, a neglected area is the junction of the external wall and other items such as the roof, windows, balconies, etc. In essence, the exterior weather-resistant barrier needs to be continuous so that there is a complete encapsulation of the exterior envelope of the buildings. The following details provide essential information for detailing these junctions. Refer to Figures 34 and 35.

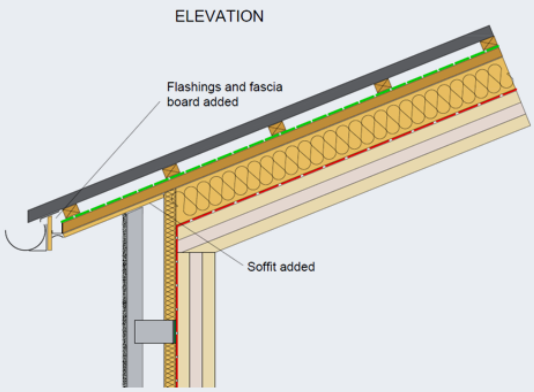


Figure 34a: Junction between a mass timber exterior wall and inclined roof

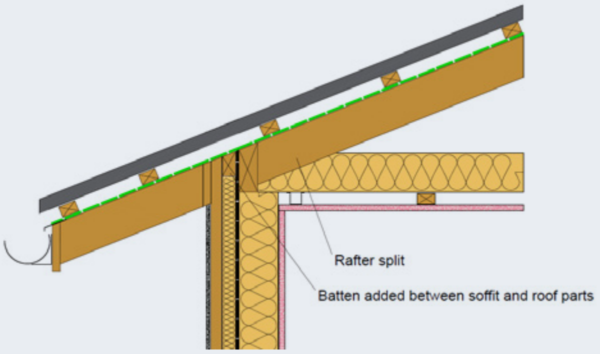


Figure 34b: Junction between a timber-framed exterior wall and pitched roof

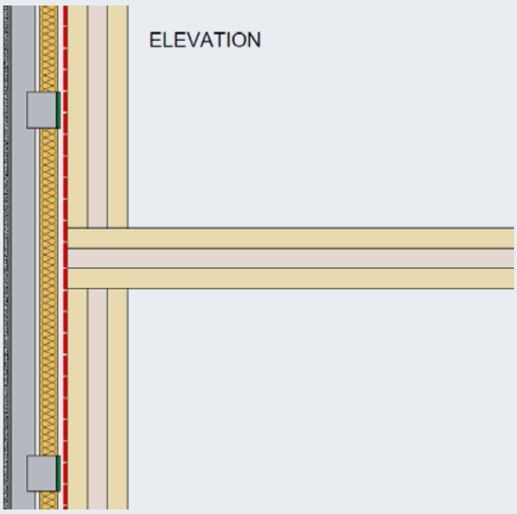


Figure 35a: Junction between the exterior wall and floor system

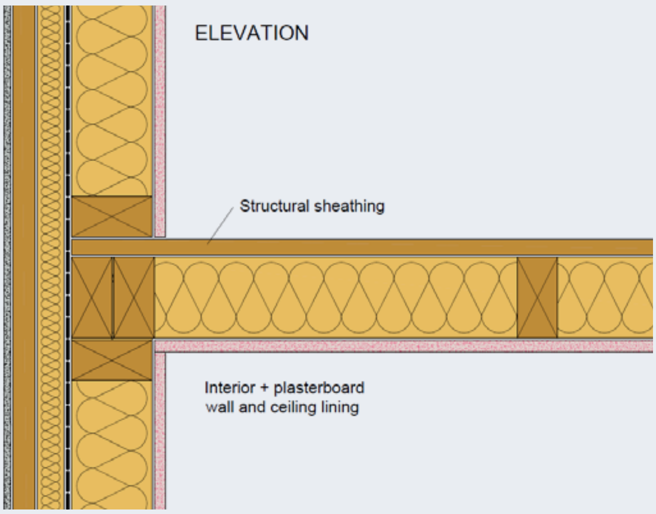


Figure 35b: Junction between a timber-framed exterior wall and floor system

10 Conflict with Other NCC Provisions

Building regulations often have conflicting requirements, and it is up to the building designer to balance these conflicts for the building's best outcome. Condensation management is no exception, where obtaining the best outcome requires consideration of other building regulations. The following discusses some of these conflicts.

10.1 Fire Resistance External Walls

Other than for houses, domestic-type structures and low-level (NCC's Type C construction), the NCC requires all parts of the external wall to be made from non-combustible materials when required to be fire-rated. Refer to the NCC for a definition of non-combustible materials. The exception is that the NCC has a concession for structural timber elements that meet the "fire-protected timber" requirements and for the pliable membrane. For further information on fire-protected timber, WoodSolutions Guide No 37 R[13] and C[14] and 38[16] provide advice on fire-protected timber design, use and background.

10.1.1 Non-Combustible Insulation

Where non-combustible insulation is required, this limits the selection of mineral fibre insulation materials to only stonewool and some glasswool. Not all glasswool passes the non-combustible test. Confirming that the product complies with the NCC non-combustibility requirement is recommended.

Compared to rigid board insulation products such as PIR, note that this requires more distance between the external facade and the mass timber to achieve equivalent thermal performance. The insulation must pass AS1530.1[12] and meet other requirements, discussed in the Fire-resistance of the external wall section of this guide.

10.1.1.1 Pliable Building Membranes versus Sarking Type of Materials

The NCC's DTS Part C1, C2D10 Non-combustible building elements have an exemption for sarking-type materials that don't exceed 1 mm in thickness. These materials may be used wherever a non-combustible material is required as long as they have a Flammability Index not greater than 5, according to AS 1530.3[17].

However, the NCC does not directly exempt Pliable Building Membranes and is considered an oversight, as sarking type materials are Pliable Building Membranes. The NCC defines a Pliable Building Membranes as a water barrier as classified by AS/NZS 4200.1[7], while the sarking type of material is a material such as reflective insulation or other flexible membranes of a type customarily used for a purpose such as waterproofing, vapour management or thermal reflectance. Where sarking-type materials are used for weatherproofing, they must also comply with AS/NZS 4200.1[7].

Therefore a sarking-type material membrane and Pliable Building Membranes are for all intended purposes are the same, therefore, can be used within exterior walls that are required to be non-combustible.

11 Summary

There are five fundamental design principles to ensure that the intestinal spaces of a building envelope don't cause condensation issues.

- Timber is not positioned on the external envelope cold side, i.e. insulation is on the outside face
- Vapour open walls to allow internal moisture to diffuse to the exterior
- Warm roofs to be appropriately designed to avoid moisture traps in service; consult specific warm roof design guidance
- Avoid water traps during installation and in-service where leaks can occur.
- Effective ventilation of the occupied interior and roof spaces and cavities

The key installation principles are:

- The installers understand and have knowledge of timber as a construction material
- Poor workmanship and interference by follow-on trades can occur if not supervised
- Stormwater management is carried out on the construction site, and temporary timber protection is used, particularly for the end grain that can be exposed to wetting during construction.

12 Acknowledgement

The author wishes to thank Protor Group Australia and FabricFirst for their input and guidance in developing this guide.

13 References

1. Scoping Study of Condensation in Residential Buildings Final Report, ABCB, 2016
2. Woodsolution Guide No. 53 Moisture management Mass Timber Buildings
3. Woodsolution Guide No. 54 Moisture management Timber Framed Buildings
4. National Construction Code Volumes 1 and 2, ABCB, 2019
5. BS 5250 Code of practice for control of condensation in buildings, British Standards Institution, 2011
6. AIRAH, DA07 Criteria for Moisture Control Design Analysis in Buildings, 2020
7. AS/NZS 4200.1: Pliable building membranes and underlays Materials, Standards Australia, 2017
8. AS/NZS 4200.2: Pliable building membranes and underlays Installation, Standards Australia, 2017
9. Condensation in Buildings Handbook, ABCB, 2014
10. National Construction Code – Guide to Volume One, ABCB, 2019
11. DA20 Humid Tropical Air Conditioning, AIRAH Application Manual
12. AS 1530.1, Methods for fire tests on building materials, components and structures Combustibility test for materials, Standards Australia, 1994
13. Wood Solution Guide No 37 R, Mid-rise Timber Buildings Multi-residential Class 2 and 3, FWPA 2016
14. Wood Solution Guide No 37 C, Mid-rise Timber Buildings Commercial and Education Class 5, 6, 7, 8 and 9b (including Class 4 parts), FWPA, 2016
15. AS 4201.4 Pliable building membranes and underlays - Methods of test Resistance to water penetration, Standards Australia, 2020
16. Wood Solution Guide No 38, Fire Safety Design of Mid-rise Timber Buildings, FWPA, 2016
17. AS 1530.3, Methods for fire tests on building materials, components and structures Simultaneous determination of ignitability, flame propagation, heat release and smoke release, Standards Australia, 2016
18. AS 1668.2, The use of ventilation and air-conditioning in buildings Part 2: Ventilation design for indoor air contaminant control (excluding requirements for the health aspects of tobacco smoke exposure), Standards Australia, 2002
19. ANSI/ASHRAE 62 Outdoor Air requirements for Ventilation of Residential Facilities (Private Dwelling, Single Multiple) Modelling Parameters
20. ANSI/ASHRAE 160 Criteria for Moisture-Control Design Analysis in Buildings, 2016
21. WoodSolutions Guide No 5: Timber Service life design
22. AS 4859.2 Thermal insulation materials for buildings Design, 2018

Appendix A: Verification Modelling Assumptions

The verification modelling was carried out by Fabricfirst, who have used the WUFI® software suite, the standard program for evaluating moisture conditions in building envelopes. The WUFI® program takes into account (where appropriate) built-in moisture, driving rain, solar radiation, long-wave radiation, capillary transport, and summer condensation.

The modelling used a 5-years duration and investigated climate conditions for

- Climate Zone 2 – Brisbane (includes the coastal area from Port Macquarie (NSW) to Mackay (Qld))
- Climate Zone 5 – Adelaide, Perth and Sydney and their surrounding areas.
- Climate Zone 6 – Melbourne (includes the coastal zone from Wollongong (NSW) around the South East of Australia to Adelaide and a region around Albany (WA))
- Climate Zone 7 – Hobart and ACT (includes the highland regions of Tasmania, Victoria and NSW)

A.1 WUFI Inputs and Building Information

The following discusses the inputs used in the hygrothermal assessment. The inputs are deemed worst-case, such as wall construction exposed to high winter internal and external moisture loads.

Table A1: WUFI Input Summary for Analysis

WUFI Settings	Assumptions	Building Typology
Grid	Fine (60 x 60)	Fine = Highest quality assessment
Orientation	Southeast (Brisbane), Southwest (Melbourne), South (Sydney), South (Hobart).	An idealised orientation as per the plan has been assumed for all the details.
Inclination	90 ° (Vertical), 22°, 3° (Horizontal)	Subject to assembly type
Driving Rain Coefficients	DA07 - Criteria for Moisture Control Design	Wall: Sheltered Rain exposure factor (FE) = 1.0 (under 10 meters high, medium), Rain deposition factor (FD) = 0.5 (walls below a low-slop roof)) Roof: R1 = 1, R2 = 1
External Heat Resistance	Wall - 0.058 m²K/W Roof - Wall - 0.0526 m²K/W	The heat transfer coefficient governs the heat exchange between the component and the surroundings.
Ext Short-Wave Radiation Absorptivity	0.5	Assumed to be 0.5, to represent a medium-coloured external finish.
Ext Long-Wave Radiation Emissivity	0.9 (Inc. Explicit Radiation Balance)	Assumed to be 0.9, to represent a medium-coloured external finish.
Int Heat Resistance	0.125 m²K/W	The heat transfer coefficient governs the heat exchange between the component and the surroundings.
Initial Relative Humidity	80%	DA07 assumption that all materials across the assessment have high water content (kg/m³)
Initial Outdoor Temp	20°C, 14.4°C, 18.1°C, 12.6°C	Assumes average yearly dry bulb temperature
Outdoor Climate	Brisbane, Melbourne, Sydney and Hobart	Metronorm 7.2 a meteorological reference program that gives access to a catalogue of meteorological data for building design.
Indoor Climate	DA07 - Criteria for Moisture Control Design	336 m³, 3 bedroom home. Air exchange rate of 0.35
Calculation Period	1/05/2020 (12 am) – 2/05/2030 (12 pm)	Ten years.

The following are additional assumptions

- AC Type – air conditioning has been assumed for all the wall and roof systems.
- Set Points – the points are referenced from NCC JVB modelling parameters (JV3 reference modelling) and used for the analysis.
- Internal Moisture – 3 bedrooms have been assumed with a building volume of 336 m3
- Air Exchange Rates – 0.35 air changes per hour have been used as per ANSI/ASHARE 62[19].

A.2 Method and Interpreting Results

The following discusses the process taken to conduct the modelling study.

A.2.1 Process

The process laid out in DA07 Criteria for Moisture Control Design Analysis in Buildings[6] is a modified text adoption of ANSI/ASHRAE 160[20]. The moisture performance evaluation criteria and reporting requirements have been used within this study, as per the process below.

A.2.2 Material Sensitivity

The prevention of wood decay requires that the mass-specific water content of wood may not exceed 20 mass-per cent over prolonged periods, as detailed in WoodSolutions Guide No 5: Timber Service life design[21]. Similar criteria apply to organic fibre insulations, such as cellulose fibres or textile fibres.

A.2.3 Relative Humidity, Water Content and Temperature

Relative humidity (%) is presented only for the surface and the exterior 10 mm of the insulation or structural timber layer. This area is deemed to be the most significant area of risk from a condensation and mould perspective.

Moisture Content (M %) is used as an additional check to assess the risk of moisture build-up and liquid water run-off into the exterior cavity. Analogous to Relative Humidity, results are presented for only the exterior 10 mm of the timber layer.

Temperature is used as an additional check to assess the risk of reaching dew point temperature in the insulation layer / cavity. Analogous to Relative Humidity, results are presented for only the exterior 10 mm of the timber layer.

A.2.4 Initial Moisture Content

An assumed initial moisture content of construction materials at the beginning of a hygrothermal study. DA07 Criteria for Moisture Control Design Analysis in Buildings [6] specifies and assume moisture content as detailed below

- Concrete = is two times Equilibrium Moisture Content 90 for concrete. EMC90 is the moisture content of a material expressed as a ratio of the mass of water and the oven-dry mass when the material is in equilibrium with air at 90% RH at 20°C.
- Other materials (including timber) = one times EMC80 for all other materials unless procedures to dry construction materials and/or procedures to protect construction materials and assemblies from wetting during construction are specified. EMC80 is the moisture content of a material expressed as a ratio of the mass of water and the oven-dry mass when the material is in equilibrium with air at 80% RH at 20°C.

A.2.5 Mould Growth Index

To minimise problems associated with mould growth on the surfaces of components of building envelope assemblies, the mould index, calculated following DA07 - Criteria for Moisture Control Design: Equations 6-1 through 6-7, shall not exceed a value of 3 and not continue to grow after the study period.

The building material surface under analysis, either timber, timber or insulation, has been assigned to one of the following four sensitivity classes:

- Very Sensitive - Untreated wood; includes lots of nutrients for biological growth
- Sensitive (Timber)- Planned wood, paper-coated products, wood-based boards
- Medium Resistant (insulation) - Cement or plastic-based materials, mineral fibres
- Resistant - Glass and metal products, materials with efficient protective compound treatments

A.2.6 Air Changes per Hour

Air changes per hour, abbreviated ACPH or ACH, or air change rate, is a measure of the air volume added to or removed from a volume or space in one hour, divided by the volume of the space. In the modelling, an ACH of 8 has been used in all wall systems and an ACH of 35 in roof systems.

To achieve an ACH of 8 in walls is considered a slightly ventilated cavity. Firstly, a cavity must be behind the cladding to achieve this, as no cavity results in little air change. The modelling assumes a 20 mm gap, except for brick veneer, where 25 mm is assumed due to NCC requirement.

Multiple factors will determine the air change rate in cavities, such as the microclimate, building orientation, cavity width, cladding material properties and colour. Consider as a minimum the provisions from AS 4859.2: [22] Clause 4.2(a) for the opening size of a slightly ventilated cavity must have an opening area greater than 500 mm2 but less than 1,500 mm2 per metre on the length of the wall.

The openings must be provided at the top and bottom of the wall, providing an unobstructed drained and vented/ventilated cavity. The external wall could be broken down into segments for tall buildings, particularly in fire-rated construction, where cavity barriers are installed every storey. Also, the batten used to form the cavity must run vertically. If this is not possible, then a counter batten system must be employed.

An NCC requirement of a ventilated roof cavity is assumed for roofs, i.e. NCC Volume One Provision F8D5 or NCC Volume 2 Part 10.8 Clause 10.8.3.

A.2.7 Sample Result

The benchmark for analysed values such as Relative Humidity (%), Water Content (M%) and Temperature (Deg C) have been indicated using the red dotted line as shown in the sample below; refer to Figure A1. Only the first 10 mm of the layered interior to the secondary drainage plane has been used for timber and glass wool (facing the exterior). This depth represents the most significant risk in all systems and is also the greatest risk of mould growth.

Graphs that have values below the red dashed line have a low potential risk of condensation and mould growth.
The exception is the first 12 months, where the modelling assumes very high moisture content; therefore, occasionally, the results may appear in this zone.

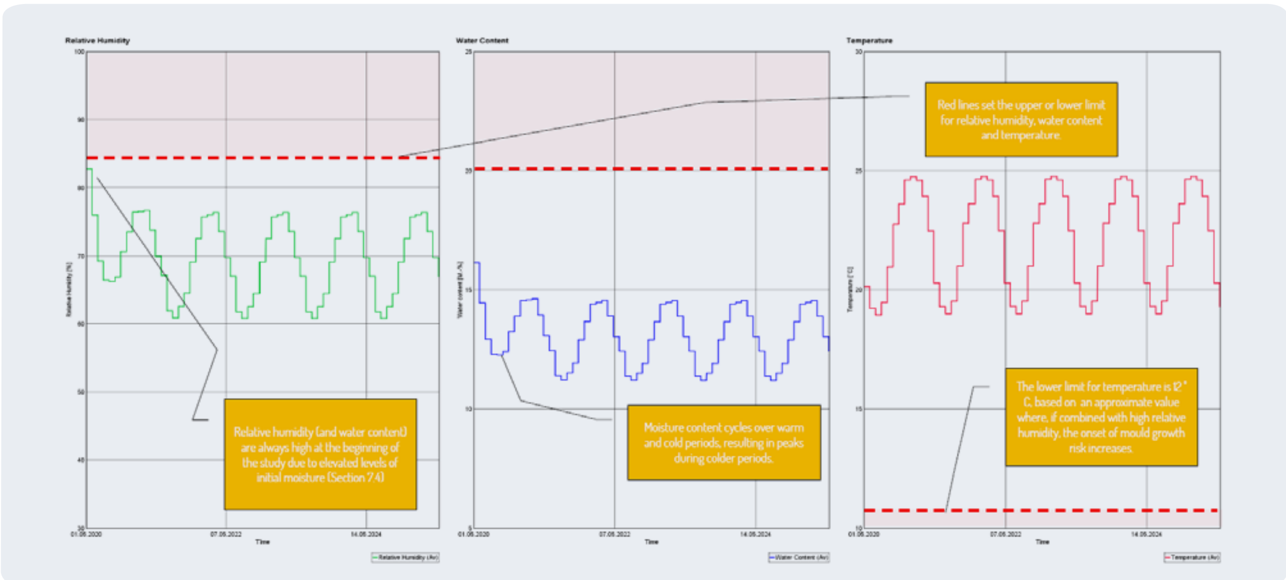


Figure A1: Sample Graph Output

Appendix B: Further Reading

- Scoping Study of Condensation in Residential Buildings Final Report, 2016
- Condensation in Buildings Handbook, ABCB, 2023
- AIRAH application manual DA20

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5 Timber service life design - design guide for durability
6 Timber-framed Construction - sacrificial timber construction joint
7 Plywood box beam construction for detached housing
8 Stairs, balustrades and handrails Class 1 Buildings – construction
9 Timber flooring - design guide for installation
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13 Finishing timber externally
14 Timber in Internal Design
15 Fire Design
16 Massive Timber Construction Systems: Cross-Laminated Timber (CLT)
17 Fire Safe Design of Timber Structures - Compliance with the NCC
18 Fire Safe Design of Timber Structures - Methods of Analysis and Supporting Data
19 Performance Solution Fire Compliance - Internal Linings
20 Fire Precautions During Construction of Large Buildings
21 Domestic Timber Deck Design
22 Thermal Performance in Timber-framed Buildings
23 Using Thermal Mass in Timber-framed Buildings
24 Thermal Performance for Timber-framed Residential Construction
25 Rethinking Construction - Consider Timber
26 Rethinking Office Construction - Consider Timber
27 Rethinking Apartment Building Construction - Consider Timber
28 Rethinking Aged Care Construction - Consider Timber
29 Rethinking Industrial Shed Construction - Consider Timber
30 Timber Concrete Composite Floors
31 Timber Cassette Floors
32 EXPAN Long Span Roofs - LVL Portal Frames and Trusses
33 EXPAN Quick Connect Moment Connection
34 EXPAN Timber Rivet Connection
35 EXPAN Floor Diaphragms in Timber Buildings
36 EXPAN Engineered Woods and Fabrication Specification
37 Mid-rise Timber Buildings (Class 2, 3 and 5 Buildings)
37R Mid-rise Timber Buildings, Multi-residential (Class 2 and 3)
37C Mid-rise Timber Buildings, Commercial and Education Class 5, 6, 7, 8 and 9b (including Class 4 parts)
37H Mid-rise Timber Buildings Healthcare Class 9a and 9c
38 Fire Safety Design of Mid-rise Timber Buildings s
39 Robustness in Structures
40 Building Timber-framed Houses to Resist Wind
41 Timber Garden Retaining Walls Up to 1m High
42 Building Code of Australia Deemed to Satisfy Solutions for Timber Aged Care Buildings (Class 9c)
43 Reimagining Wood-based Office Fitout Systems - Design Criteria and Concepts
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51 Cost Engineering of Mid-rise Timber Buildings
52 Timber Connectors
53 Moisture Management of Mass Timber Construction
54 Moisture Management of Timber Frame Construction
55 The Role of Wood Products in Zero Carbon Buildings