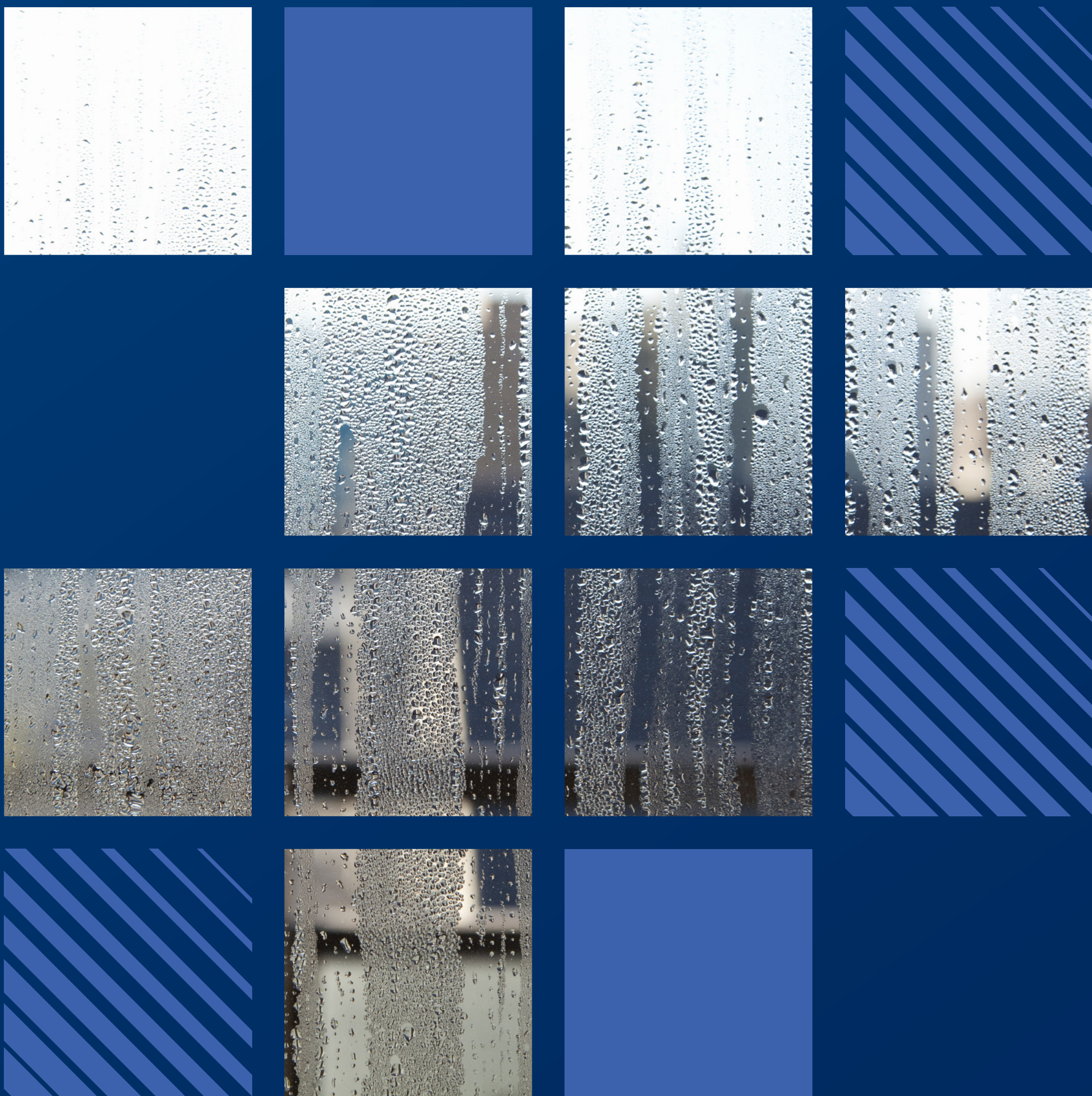
National Construction Code

Condensation in buildings

Handbook



Australian Building Codes Board

The Australian Building Codes Board

The Australian Building Codes Board (ABCB) is a standards writing body responsible for the National Construction Code (NCC), WaterMark and CodeMark Certification Schemes.

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Preface

This handbook is one of a series by the ABCB. Handbooks expand on areas of existing regulation or relate to topics that are not regulated by the NCC. They provide advice and guidance.

The Condensation in Buildings Handbook assists in understanding the condensation requirements in NCC Volumes One and Two.

It addresses issues in generic terms and is not a document that sets out specific compliance advice for developing solutions to comply with the requirements in the NCC. It is expected that this handbook guides readers to develop solutions relevant to specific situations in accordance with the generic principles and criteria contained herein.

Contents

Reminder

This handbook is not mandatory or regulatory in nature. Compliance with it will not necessarily discharge a user's legal obligations. The handbook should only be read and used subject to, and in conjunction with, the general disclaimer at page i.

The handbook also needs to be read in conjunction with the NCC and the relevant legislation of the appropriate state or territory. It is written in generic terms and it is not intended that the content of the handbook counteract or conflict with the legislative requirements, any references in legal documents, any handbooks issued by the administration or any directives by the appropriate authority.

1 Background

This handbook provides guidance to practitioners to help with assessing the risk of condensation, its consequences and the requirements of NCC Volumes One and Two.

It provides an overall introduction to the concept of condensation, causes and effects, and then discusses potential management options, including the requirements in the NCC.

Since the design approval process for Performance Solutions varies between the responsible state and territory governments, this is likely to be the case with designs incorporating Performance Solutions for condensation. Therefore requirements should be checked for the relevant jurisdiction.

The advice of an appropriately qualified person should be sought to perform this assessment and analysis where needed. This may be aided by the early and significant involvement from regulatory authorities, peer reviewer(s) and/or a technical panel as appropriate to the relevant jurisdiction.

Many buildings designed today will serve in an environment where extreme weather events are predicted to be more frequent and climatic patterns may shift. This may create unfamiliar combinations of precipitation, humidity and seasonal temperatures. Increasing insulation and air tightness are changing the underlying building physics. 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. These circumstances suggest that condensation management strategies based only on established expectations, rules of thumb or narrow margins of safety are unlikely to stand the test of coming decades.

Condensation is the result of complex interactions between the environment, building construction and occupant behaviour. The NCC has minimum requirements designed to manage risks associated with water vapour and condensation to minimise their impact on the health of occupants.

1.1 Scope

Condensation is an event which reveals the presence of water vapour in the atmosphere. When the resulting condensate is unable to dry as readily as it forms, it can accumulate to cause problematical wetting in buildings. This handbook discusses that risk and emphasises the overriding goal of keeping buildings dry, by:

- ensuring they are acceptable when constructed
- detailing them to resist the entry of weather and groundwater

- managing water vapour movement and the temperature of building surfaces it encounters
- ensuring any unavoidable damp or wetness can dry out faster than it can form.

The minimum condensation requirements in the NCC aim to reduce interstitial condensation in walls and roof spaces. However, designers, builders and building occupants can all play an important role in managing condensation. Although the NCC applies mainly to new buildings, this handbook also offers advice for occupants of existing buildings where condensation has become a real or anticipated concern.

Since the design of new buildings is subject to regulatory requirements in the NCC, Chapter 2 reviews how these requirements might constrain or encourage approaches to manage condensation risks. This includes the Performance Requirements, Verification Methods and DTS Provisions for condensation management in Volumes One and Two.

Many of the situations discussed refer to homes or domestic construction. Homes are mainly designed and built with limited access to specialist advice on potential risks arising from new materials and methods of construction. When they are renovated, changes which might reduce the building enclosure's ability to stay dry are not always recognised.

Commentary and examples relevant to larger commercial buildings are noted where they occur, but the handbook does not attempt to deal in any detail with the wide variety of indoor environments that can be found in such buildings.

The construction details and illustrations focus mostly on colder climates rather than hotter humid climates. This is because the research undertaken to develop this handbook is based on extensive overseas research and experience with condensation management currently available. Where possible, these details have been customised to Australian conditions, however, this was not possible in all instances.

1.2 Using this document

Acronyms used in this document are in Appendix A.

General information about complying with the NCC and responsibilities for building and plumbing regulation are in Appendix B.

A glossary of terms used in this document are in Appendix C.

Supplementary material is in Appendix D.

Key Australian and International condensation standards are in Appendix E.

References and further reading is in Appendix F.

Different styles are used in this document. Examples of these styles are:

NCC extracts[1]

Examples

Alerts or Reminders

[1] NCC extracts italicise defined terms as per the NCC. See Schedule 1 of the NCC for further information.

2 Condensation management in the NCC

This chapter explains the key concepts of the NCC's condensation management requirements. These NCC requirements aim to reduce the likelihood of condensation or water vapour build-up causing illness, injury or loss of amenity for building occupants. The condensation management requirements apply to the following residential buildings:

- Class 1 buildings
- Sole-occupancy units of Class 2 buildings
- Class 4 parts of buildings.

The NCC 2022 condensation management requirements build upon the initial condensation management requirements introduced into NCC 2019.

The requirements are located in the following sections:

- Part F8 of NCC Volume One
- Part H4 of NCC Volume Two
- Part 10.8 of the ABCB Housing Provisions ('Housing Provisions').

As part of these requirements, the NCC adopts a number of referenced documents, such as Australian Standards and industry standards. These documents are relevant to building design, the installation of insulation and selection of climate appropriate building membranes. All these factors influence the approaches available to managing condensation risk.

2.1 Performance Requirements

The Performance Requirements are the mandatory requirements of the NCC. For condensation management, these are F8P1 and H4P7 in Volume Ones and Two, respectively. These Performance Requirements did not change in NCC 2022 (compared to NCC 2019).

An excerpt of the Performance Requirements from NCC Volumes One and Two follows.

F8P1 Condensation and water vapour management

Risks associated with water vapour and *condensation* must be managed to minimise their impact on the health of occupants.

Applications:

F8P1 only applies to a *sole-occupancy unit* of a Class 2 building or Class 4 part of a building.

H4P7 Condensation and water vapour management

Risks associated with water vapour and *condensation* must be managed to minimise their impact on the health of the occupants.

Applications:

H4P7 only applies to a Class 1 building.

2.2 Verification Method

One option for demonstrating compliance with the Performance Requirements F8P1 and H4P7 for condensation and water vapour management is with a Performance Solution such as Verification Method F8V1 or H4V5.

A Performance Solution is an optional approach to demonstrating compliance with the NCC Performance Requirements for condensation and water vapour management.

A Performance Solution can provide flexibility where the prescriptive DTS Provisions are considered too rigid or inappropriate for the particular building design. Assessment Methods, such as these Verification Methods, provide pathways that can be followed to achieve a Performance Solution.

The flexibility offered by these Verification Methods can assist in creating an innovative built environment, but they are not mandatory. Building designers should consider whether the Verification Method, the prescriptive DTS Provisions, or another Performance Solution is most appropriate for their project.

More information on NCC compliance options is located in Appendix B.

Significant updates were made to these Verification Methods for NCC 2022. Rather than a qualitative requirement, the Verification Methods F8V1 and H4V5 have been quantified. This means they include a measurable criteria that must be met for a proposed design. The Verification Methods can be used to demonstrate compliance for a roof or external wall assembly. An excerpt of F8V1 is shown below, noting that H4V5 has the same text with relevant Volume Two cross-references (i.e. H4P7 instead of F8P1).

F8V1 Condensation management

(1) Compliance with *Performance Requirement* F8P1 is verified for a roof or *external wall* assembly when it is determined that a mould index of greater than 3, as defined by Section 6 of AIRAH DA07, does not occur on –

(a) the interior surface of the *water control layer*; or

(b) the surface of building *fabric* components interior to the *water control layer*.

(2) The calculation method for (1) must use –

(a) input assumptions in accordance with AIRAH DA07; and

(b) the intermediate method for calculating indoor design humidity in Section 4.3.2 of AIRAH DA07.

The main changes to this Verification Method are new references to a guide produced by the Australian Institute for Refrigeration, Air conditioning and Heating (AIRAH). The guide is AIRAH DA07 Criteria for Moisture Control Design Analysis in Buildings (2021).

AIRAH DA07 provides performance-based design criteria for predicting, mitigating or reducing moisture damage to the building envelope, materials, components, systems, and furnishings based on a range of factors. The methods of AIRAH DA07 may be used with software packages capable of completing hygrothermal calculations. Further information on AIRAH DA07 is provided in Appendix E.1.4 of this handbook.

The Verification Method requires confirmation that a roof or external wall assembly has a mould index less than or equal to 3 on either the interior surface of the water control layer, or on the surface of building fabric components interior to the water control layer.

A water control layer means a pliable building membrane or the exterior cladding when no pliable building membrane is present. A pliable building membrane is a water barrier as classified by AS 4200.1.

The mould index must be calculated using the input assumptions and intermediate method for calculating indoor design humidity from Section 4.3.2 of AIRAH DA07.

A mould index equal to 3 is described as visual findings of mould on the surface of a material with less than 10% coverage, or 50% coverage of mould under a microscope. Mould index values less than 3 correspond with mould growth only visible under a microscope.

Section 6 of AIRAH DA07 provided a set of input assumptions that can be used with hygrothermal analysis software to calculate the mould index. These input assumptions include the mould sensitivity class of a material, humidity and time.

The mould sensitivity class of a material is its potential to develop mould. For example, glass and metal are grouped into a low mould sensitivity class and are therefore considered resistant to mould growth. Untreated wood contains nutrients that enable biological growth and is therefore classified as very sensitive to mould growth.

To calculate the mould index, the Verification Method also requires the use of input assumptions from AIRAH DA07, specifically Section 4.3.2 Indoor Design Humidity, Intermediate Method. This provides a standardised method for determining the indoor design humidity using hourly weatherly data and the type of HVAC equipment likely to be used. Using this approach helps ensure consistent input assumptions and calculation methods for indoor humidity are used to calculate the mould index.

2.3 DTS Provisions

The DTS Provisions are a prescriptive approach to comply with Performance Requirements F8P1 and/or H4P7.

NCC Volume One, Part F8 outlines that compliance with Performance Requirement F8P1 is satisfied by complying with the DTS Provisions F8D2 to F8D5.

Similarly, NCC Volume Two states that Performance Requirement H4P7 is satisfied by complying with Part 10.8 of the Housing Provisions.

2.3.1 External wall construction

To facilitate the removal of water vapour from a wall, the NCC requires a pliable building membrane be permeable to water vapour in certain locations. This is because in cooler climates if internal spaces are heated for parts of the year, the risk associated with trapped moisture can negatively affect building elements and the health of the occupants. The permeability of the membrane not only reduces instances and severity of condensation but improves drying potential when condensation occurs.

Alert

Vapour permeance means the degree that water vapour is able to diffuse through a material, measured in µg/N.s (micrograms per newton-second) and tested in accordance with the ASTM-E96 Procedure B – Water Method at 23°C 50% relative humidity (RH).

The vapour permeance of vapour control membranes (VCM) are classified in reference documents AS 4200.1 (previously AS/NZS 4200.1) and AS 4200.2. An excerpt of the VCM classification is shown below in Figure 2.1.

Figure 2.1 Vapour control membrane (VCM) classification (Source: AS 4200.1:2017)[2]

VAPOUR CONTROL MEMBRANE (VCM) CLASSIFICATION

		Vapour permeance (see Note) µg/N.s	
Class	**VCM category**	**Min. (≥)**	**Max. (<)**
Class 1	Vapour barrier	0.0000	0.0022
Class 2		0.0022	0.1429
Class 3	Vapour permeable	0.1429	1.1403
Class 4		1.1403	No max.
	ASTM-E96 Method B Wet Cup—23°C 50%RH		

NOTE: Vapour permeance is the inverse of vapour resistance. It shall be calculated as follows:

Vapour permeance µg/N.s = 1/ (Vapour resistance MN.s/g)

VCMs are broken up into four classifications. Class 1 and 2 represent membranes considered to be vapour barriers, and Class 3 and 4 are considered to be vapour permeable. The classification of VCMs should not be confused with building classifications used in the NCC.

The NCC requires a pliable building membrane and secondary insulation layers on the outside of primary insulation in an external wall to be vapour permeable. This varies with climate zone as follows in:

- climate zones 4 and 5, a VCM that is Class 3 or Class 4 is required
- climate zones 6, 7 and 8, a VCM that is Class 4 is required.

Open-cell insulation, such as mineral wool or fibreglass, typically has a high vapour permeance, while closed-cell insulation, such as polystyrene, typically has a low vapour permeance. Many foil-faced insulation products have a low vapour permeance.

F8D3(3) of NCC Volume One and 10.8.1(3) of the Housing Provisions provides specific requirements where a pliable building membrane is not used. These requirements do not

[2] Reproduced from AS 4200.1:2017 by the ABCB. © Standards Australia 2017. Users must not copy or reuse this work without the permission of Standards Australia.

apply to an external wall that is a single skin masonry or single skin concrete. Where a pliable building membrane is not installed in an external wall, the primary water control layer must be separated from water sensitive materials by a drained cavity.

The intent of this clause is to ensure that when no wrap or sarking type material is used, a drained cavity is installed between the primary water control layer and any water sensitive materials.

This clause is not intended to allow substitutions where untested vapour permeable materials are installed instead of a pliable building membrane. This means that untested vapour permeable materials should not be used as there is a potential for condensate to accumulate and damage water sensitive materials.

2.3.2 Exhaust systems

The DTS Provisions in NCC Volume One and the Housing Provisions specify minimum requirements for the flow rates of exhaust systems for bathrooms, sanitary compartments, kitchens and laundries[3]. A sanitary compartment refers to a room or space containing a toilet (closet pan) or urinal.

In NCC 2022, exhaust from a kitchen, kitchen range hood, bathroom, sanitary compartment, or laundry must be discharged to outdoor air, either directly, or via a duct or shaft.

Where a venting clothes dryer is installed, it must discharge directly or via a shaft or duct to outdoor air. (Note this requirement does not apply to condensing clothes dryers, since these appliances capture water vapour as the clothes dry and condense it into liquid water that can be disposed of.) Where no clothes dryer is installed in a Class 2 sole-occupancy unit but space for a clothes dryer is provided in accordance with F4D2(1)(b), space must also be provided to duct a clothes dryer to the outdoors.

The intent of these new provisions is to reduce the amount of moist air entering a home, including the roof cavity, as this can lead to increased condensation build-up and its associated risks.

F8D4(5) and 10.8.2(4) of NCC Volume One and the Housing Provisions identify what is required when a bathroom or sanitary compartment is not naturally ventilated or continuously mechanically ventilated. The room's exhaust system must be interlocked to the room's light switch with a timer that runs the exhaust system for 10 minutes after the light has been switched off.

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[3] The intent of 10.8.2(1) is to ensure an exhaust system has a minimum flow rate when the room or space is being used by an occupant. This does not prevent it being run continuously at a low flow rate when the room or space is not being used by an occupant.

10.8.2(5) and (6) of the Housing Provisions and F8D4(6) of NCC Volume One require some rooms that have exhaust systems and are not naturally ventilated (e.g. rooms without openable windows) to be provided with make-up air.

F8D4(6) of NCC Volume One requires such rooms with space for ducting a clothes dryer to outdoor air, be provided with make-up air in accordance with AS 1668.2.

The make-up air requirements of 10.8.2(5) are based on minimum flow rates specified in 10.8.2(1). Make-up air provision can be achieved via openings to an adjacent room with a free area of 14,000 mm^2 (e.g. a 20 mm undercut to a 700 mm wide door). Alternatively, make-up air can also be provided in accordance with AS 1668.2.

Alert

The requirements of 10.8.2 of the Housing Provisions and F8D4 of NCC Volume One may involve penetrations through wall/ceilings with a fire separation requirement. Fire separation must not be compromised by the requirements of 10.8.2 of the Housing Provisions and F8D4 of NCC Volume One.

2.3.3 Ventilation of roof spaces

Considerable amendments have been made to the roof ventilation requirements in NCC 2022, specifically in climate zones 6, 7 and 8.

F8D5 in NCC Volume One and 10.8.3 of the Housing Provisions outlines the minimum requirements for:

- the location of sarking and/or the primary insulation level relative to roof space
- the minimum roof space height, and
- what is deemed adequate ventilation for a roof space to minimise condensation risk.

Tables F8D5 in NCC Volume One and 10.8.3 of the Housing Provisions provide the requirements for ventilation openings for roofs with varying pitches.

F8D5(2) and 10.8.3(2) states if a roof is made of concrete or structural insulated panels, or is subject to Bushfire Attack Level Flame Zone (BAL-FZ) requirements, F8D5(1) in NCC Volume One and 10.8.3(1) of the Housing Provisions do not apply.

3 Condensation concepts

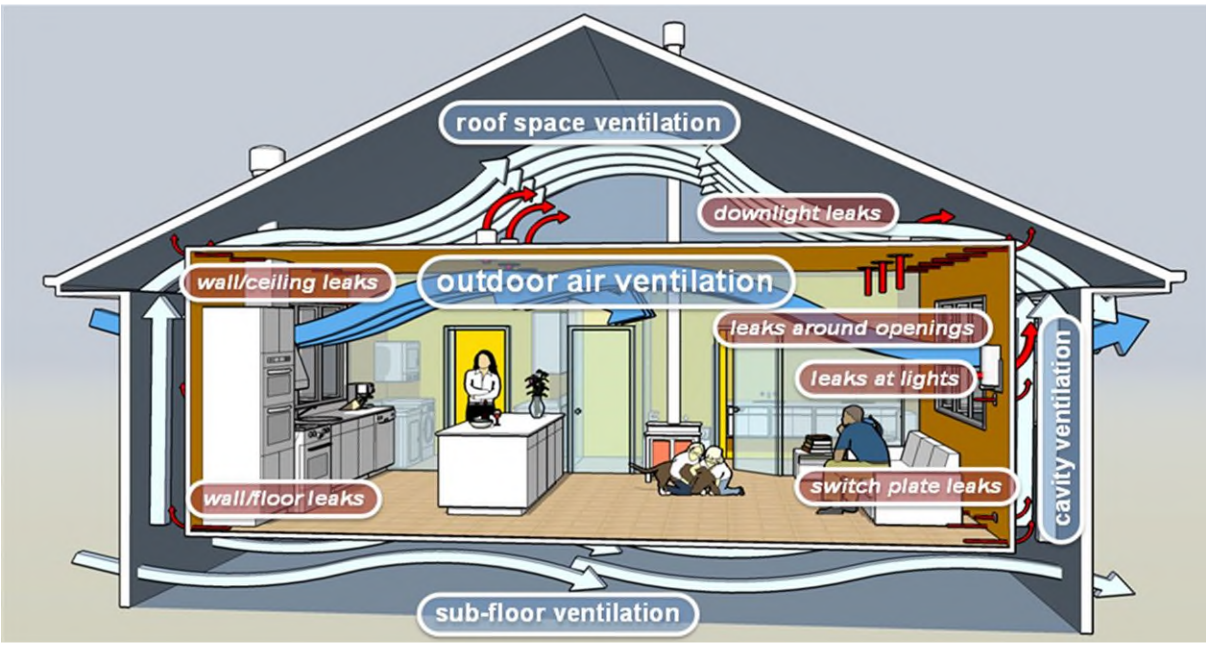
3.1 Overview

This chapter covers fundamental condensation concepts such as water vapour, climate and relative humidity (RH).

Even a dry building contains water. Some is confined in pipes, drains and tanks installed to make the building workable. However, it is water vapour, which is always present in the atmosphere, mixing freely with air and going wherever air goes that causes issues.

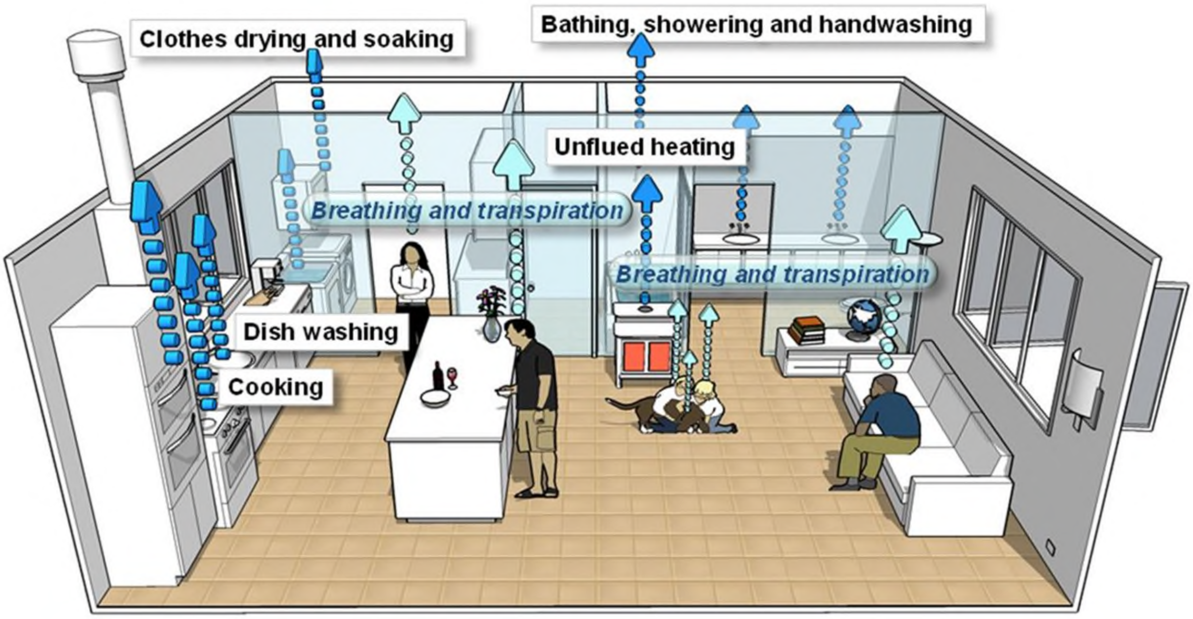
As it happens, air travels virtually everywhere in and around the rooms of our buildings (Figure 3.1). Having outdoor air indoors is vital for health and amenity, and is encouraged by flow through open windows and doors or drawn in through mechanical ventilating and air conditioning systems. Driven by fluctuating pressures around buildings, air also leaks inwards and outwards through interior linings. In addition, outdoor air is deliberately circulated through roof spaces, wall cavities and sub-floor spaces to help them dry. All of that constantly mobile air carries water vapour with it.

Figure 3.1 Air and water vapour movement through the building interior and the building fabric



Inside buildings, people release more water vapour into the air by breathing and transpiration from the skin. In homes, daily activities such as cooking, washing and showering releases more. Figure 3.2 illustrates some examples of water vapour sources that can increase RH.

Figure 3.2 Water vapour sources in a home can increase RH

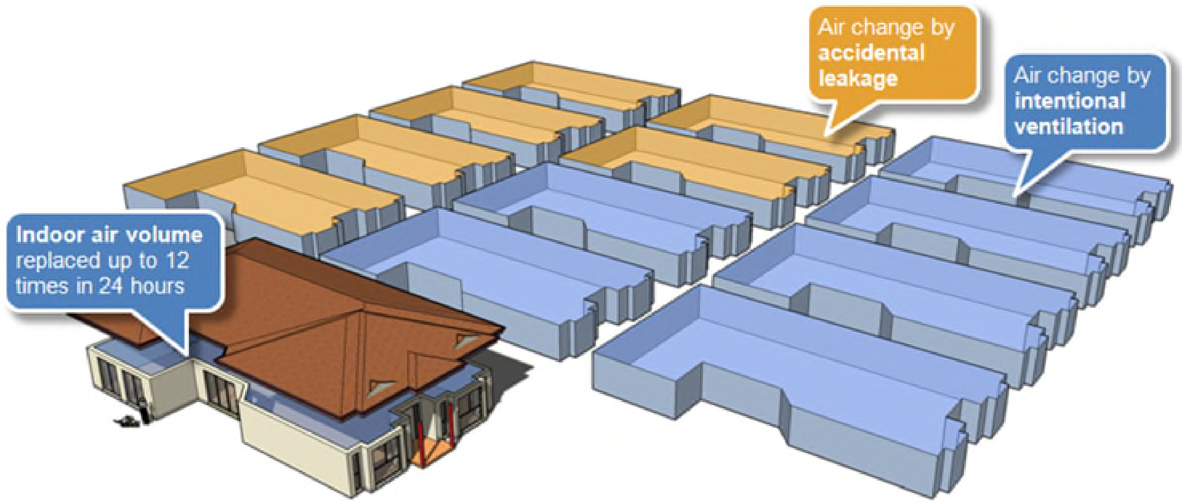


In a residential room where both temperature and humidity are closely controlled, the amount of circulating water vapour might vary from under 0.5% of the moist air mass in a cold climate up to about 1% in a warm humid climate. While this may not seem like a lot of water vapour, only a small amount of extra water vapour is needed to increase the risk of condensation related problems.

Section 3.2 discusses the behaviour and effects of accumulating water vapour and points out that even a low concentration, at a low enough temperature, can represent a high RH. RH is the amount of water vapour in the air as a percentage of the amount the air can actually hold. When RH reaches 50% or more, undesirable effects can follow.

As part of reducing these risks, an international survey of indoor air quality recommends complete replacement of the air in a home every two hours at least (NHBC, 2009). Figure 3.3 represents how much air is involved to achieve the recommended minimum ventilation rate. The diagram also highlights that even a contemporary “airtight” home will allow about half of the air (and water vapour with it) to travel through accidental pathways formed by gaps, cracks and holes in the building fabric.

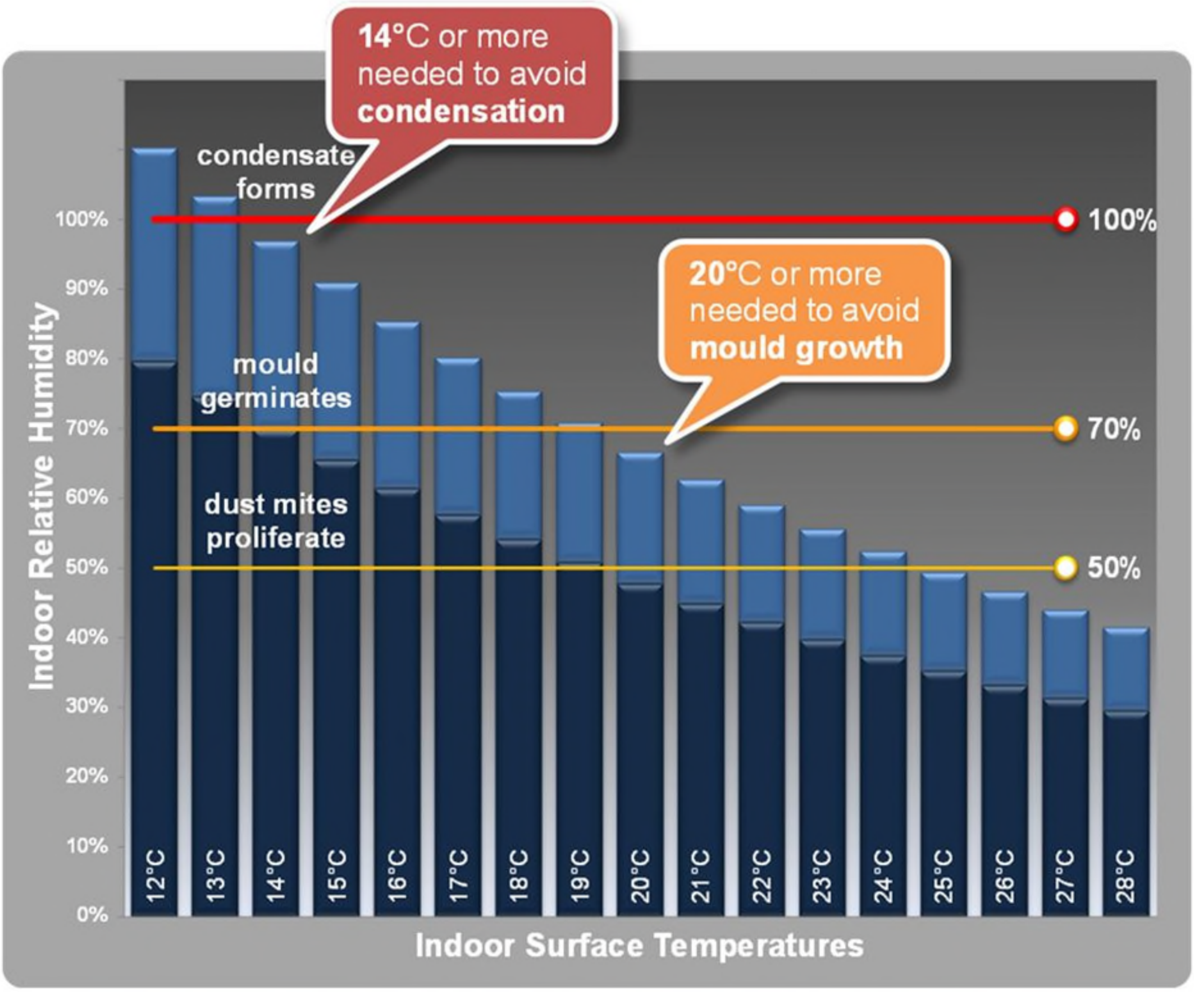
Figure 3.3 Outdoor air ventilation from outdoors for acceptable indoor air quality



Since outdoor air supply cannot safely be reduced below an essential minimum, water vapour brought in with outdoor air will limit attempts to lower water vapour levels indoors (unless an air conditioning system with substantial dehumidifying capacity is involved). Once that lower limit is reached, RH must be managed by raising the indoor temperature, using active or passive heating. The benefits of controllable heating are illustrated in Figure 3.4.

At each one-degree temperature step across the chart, the darker blue lower column shows how much outdoor air for ventilation contributes to the RH indoors. The lighter blue upper column shows the extra effect of water vapour released indoors by the occupants' activities. The RH columns in Figure 3.4 become shorter as temperatures rise although the same total amount of water vapour is involved in each case. Only the RH percentage is falling but that is enough to reduce risks of microbial growth, material degradation or surface condensation.

Figure 3.4 Reducing risks from rising RH by warming indoor surfaces



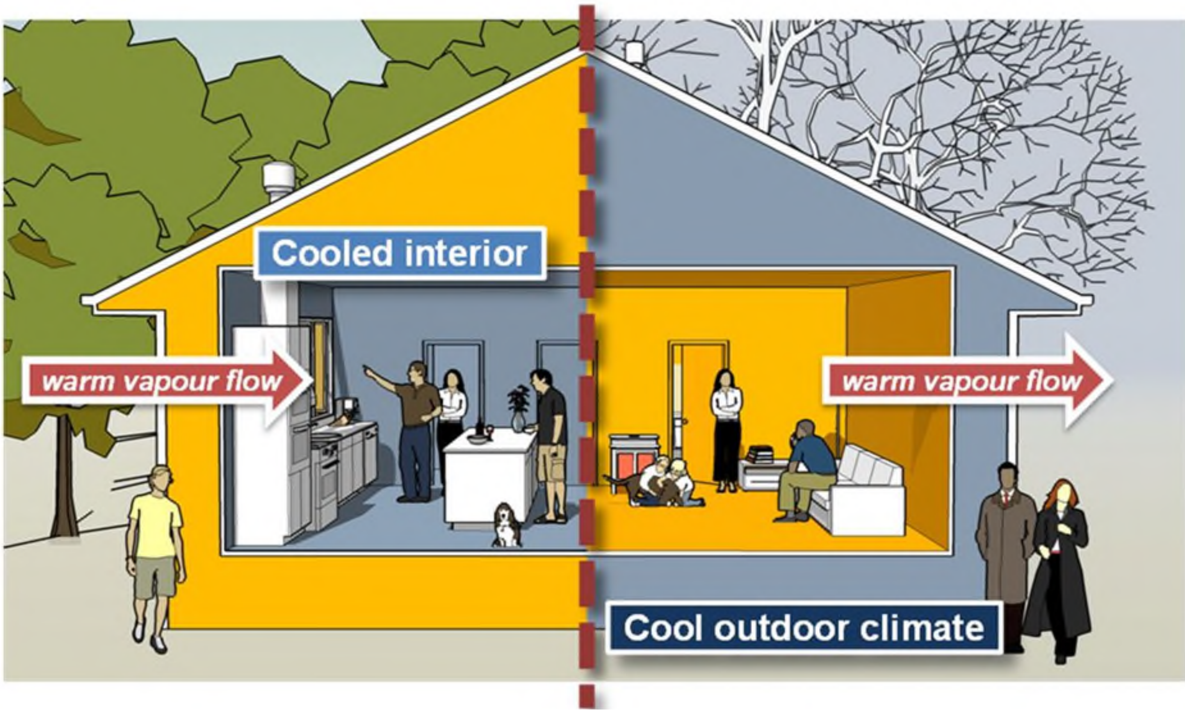
Managing RH and condensation risks indoors begins with understanding the local climate. The eight climate zones defined for the NCC energy efficiency provisions depend mainly on seasonal temperatures with some attention to summertime humidity. Outside of climate zones 1, 2 and 3, they are not reliable guides when designing and building to avoid high humidity or condensation problems.

Section 3.3 examines opportunities to apply, instead, climate statistics available online from the Bureau of Meteorology (BOM) for the numerous locations it monitors and provides suggestions for assessing comparative risk across Australia and the particular characteristics of individual places.

Risks of excessive RH and condensation are not confined to colder climates or seasons. They can happen in mild climates when water vapour is at its lowest level for the year but temperatures are also down (depressed). They can occur in the summer wet season of the humid tropics, when there is so much water vapour in the atmosphere that RH is already high and even a small fall in temperature is enough to trigger condensation.

In both situations, the critical drop in temperature can be caused by cold outdoor conditions or by using artificial cooling indoors. With air conditioning common in many types of buildings, the effects of artificially cooled interiors and of naturally cool outdoor climates both need to be considered. Refer to Figure 3.5.

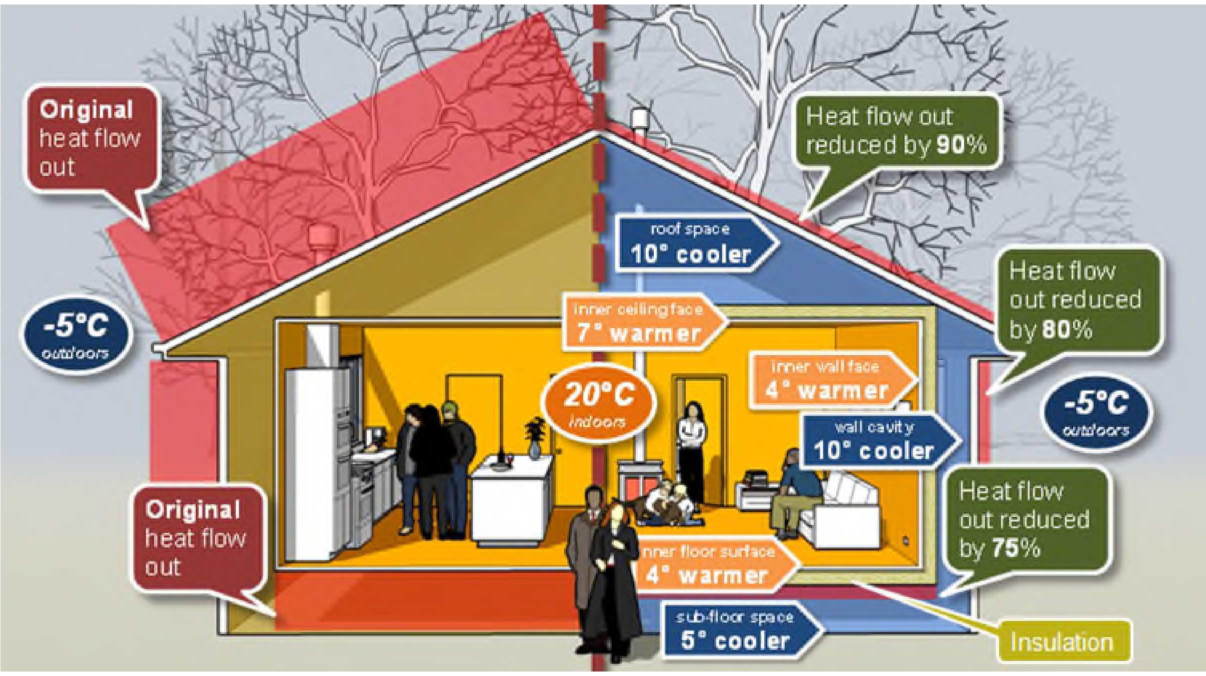
Figure 3.5 Critical temperatures driven by artificial cooling indoors or by the climate outdoors



Problems of too much water vapour meeting surfaces made too cool by air conditioning or by ambient conditions can occur in the same geographic location at different times of the year. Longstanding practices of using vapour barriers to limit water vapour migration become problematic when the source of water vapour relative to the location of critical building surfaces reverse from season to season. Experience from the milder climates of the United States (US) shows that well-intentioned but inappropriately placed vapour barriers can become critical impediments to drying when water vapour may be flowing both inwards and outwards during the year. One of the key matters to understand is how the level of insulation and its placement in the building fabric can alter surface temperatures inside rooms and within the fabric itself.

Figure 3.6 uses one of Australia's coldest climates to illustrate how insulated building fabric (on the right) can slash heat loss and raise surface temperatures indoors compared to uninsulated construction (on the left). With the benefits of warmer indoor surface temperatures and reduced risk of mould growth, comes substantial cooling of the concealed cavities and air spaces in the building fabric. Minimising the amount of water vapour that can accumulate in contact with those surfaces or keeping the surfaces warmer then becomes essential. Although smaller changes to temperature profiles will occur in milder climates, the example highlights why the configuration of building fabric assemblies needs careful attention when changes are being made to the thermal envelope.

Figure 3.6 Heat loss and temperature change effects of an insulated and uninsulated home (all added insulation is placed on the ceiling, in wall frame or under flooring)



The outward heat flows through the roof and wall on the left side of Figure 3.6 also demonstrate why an uninsulated building would have warmer cavities and air spaces. These benefits will last only while massive heat loss outwards from the warm interior can be sustained.

3.2 Water vapour

This section covers concepts related to water, water vapour, water vapour diffusion, saturation (or dew point), RH and the consequences of condensation.

3.2.1 Water

Water has the unique ability to be a solid, a liquid or a gas at ordinary temperatures. As it absorbs or loses heat, it can change from any one form directly to any other. Possibly the most exploited of these transformations is the evaporation of liquid water into its gaseous form of water vapour. We rely on evaporation, consciously or not, for drying almost everything that has become moist, damp or wet. When the same process reverses, and water vapour cools enough to condense into droplets of liquid water, the results are often unhelpful.

Condensation concealed from view inside the assemblies of materials that form the building enclosure, can accumulate into problems of water leaks, corrosion, decay and microbial hazards. Condensation in difficult places can happen as water vapour can revert to a liquid in parts of the building enclosure that water would not be expected to reach.

3.2.2 Water vapour

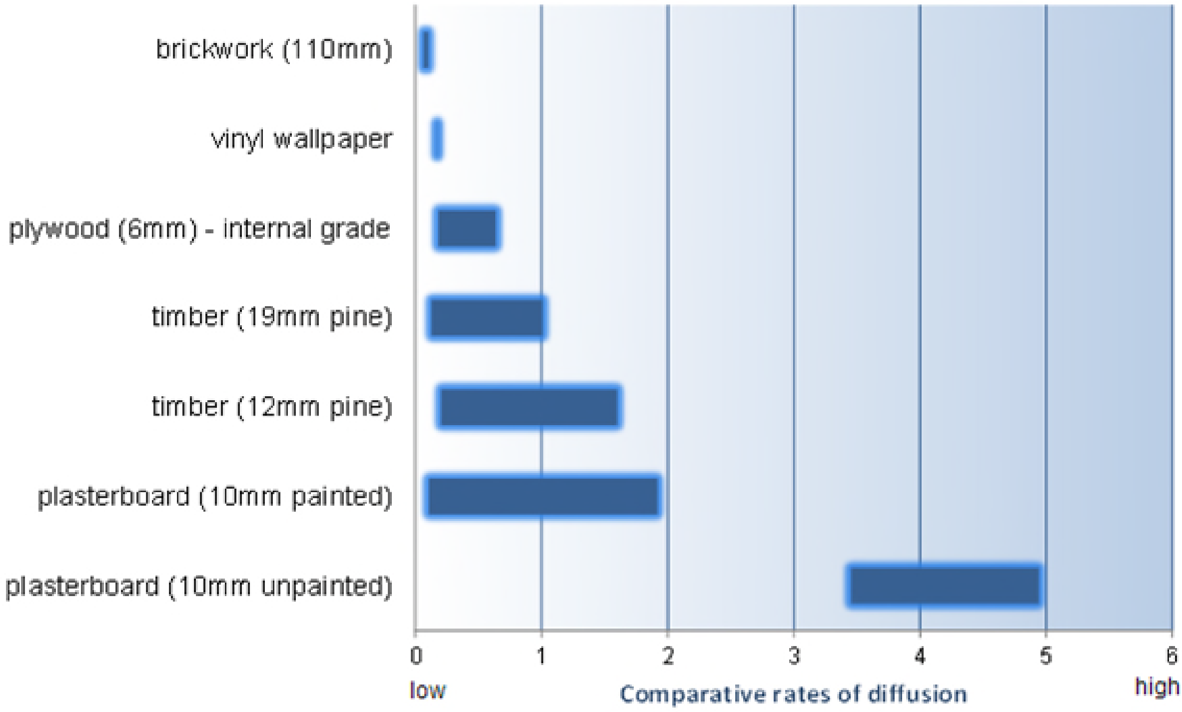
Water vapour is invisible. Clouds, fog and steam are not water vapour but are accumulations of fine, floating water droplets. Water vapour is “seen” mainly through its effects on comfort and its constant interaction with materials. A sticky day and a sticky door are, of course, two different things but water vapour helps to cause both of them.

There is always some water vapour in the atmosphere, even in the world’s driest places. In Australia, the water vapour content of the atmosphere can fall lower than 0.25% in alpine areas during winter and reach nearly 2% in the tropical north during the summer “wet”.

3.2.3 Water vapour diffusion

Because individual water vapour molecules are much smaller than liquid water, they can penetrate materials that would hold back liquid water and air. Where there is more water vapour concentrated on one side of a material than on the other, water vapour will attempt to diffuse through the material towards the lower concentration. Figure 3.7 compares rates of water vapour diffusion through some building materials which are permeable to water vapour (each bar spans a typical range for the material). Materials which are impermeable to water vapour, such as glass and most metals, effectively prevent diffusion and would not register on the chart at all.

Figure 3.7 Diffusion of water vapour through some permeable building materials (Comparison based on values from BS 5250:2011+A1:2016)



The driving force for adsorption is a difference in vapour pressure across a material or between spaces.

When it comes to diffusion, water vapour responds to differences in its own partial vapour pressure between one place and another, regardless of the overall atmospheric pressure. In practice, diffusion will rarely be 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.

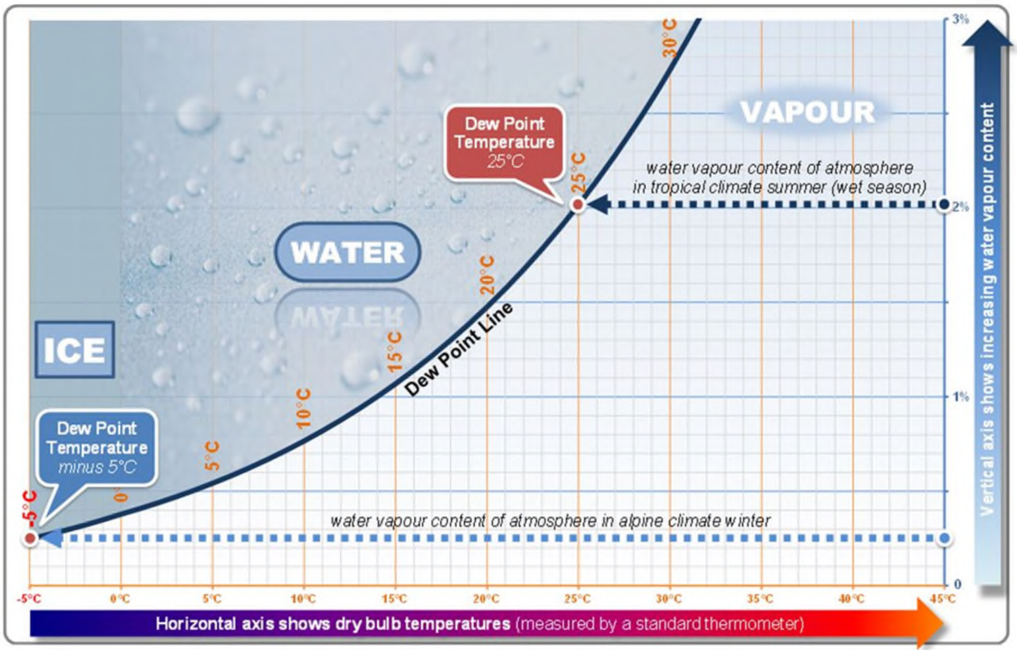
3.2.4 Saturation or dew point

Temperature determines the maximum number of molecules that can escape the surface of water by evaporation and continue to remain as vapour. When that limit is reached, the accumulated water vapour has reached a state of “saturation”. If it cools, condensate will form as a mist or droplets until the water vapour concentration is low enough for the lower temperature to sustain it.

How temperature limits water vapour accumulation can be understood when mapped on a psychrometric[4] chart. The chart in Figure 3.8 is simplified for introductory purposes.

[4] Psychrometry measures changes in the conditions of water vapour at various concentrations and temperatures.

Figure 3.8 Elements of the psychrometric chart



The key feature of the chart is the diagonal curve which separates the gridded vapour zone on the right from the ice and water zones on the upper left. The intersection of any vertical temperature line with the curve marks the saturation limit for that temperature. Reading across the chart, to the vertical axis, reveals the water vapour content of the atmosphere at that saturation limit (as a percentage by mass of the atmosphere in this version of the chart).

The saturation curve is labelled here as the “Dew Point Line”. Dew point is the temperature to which air must be cooled in order to produce condensation (dew). The higher the water vapour level, the higher the temperature of its dew point. The less water vapour present, the lower the temperature needs to fall to reach dew point. Combinations of temperature and concentration which allow water vapour to remain as vapour all fall into the gridded vapour zone. Any combination that falls above the curve will see water vapour condensing into dew (for temperatures above 0°C) or frost (below 0°C).

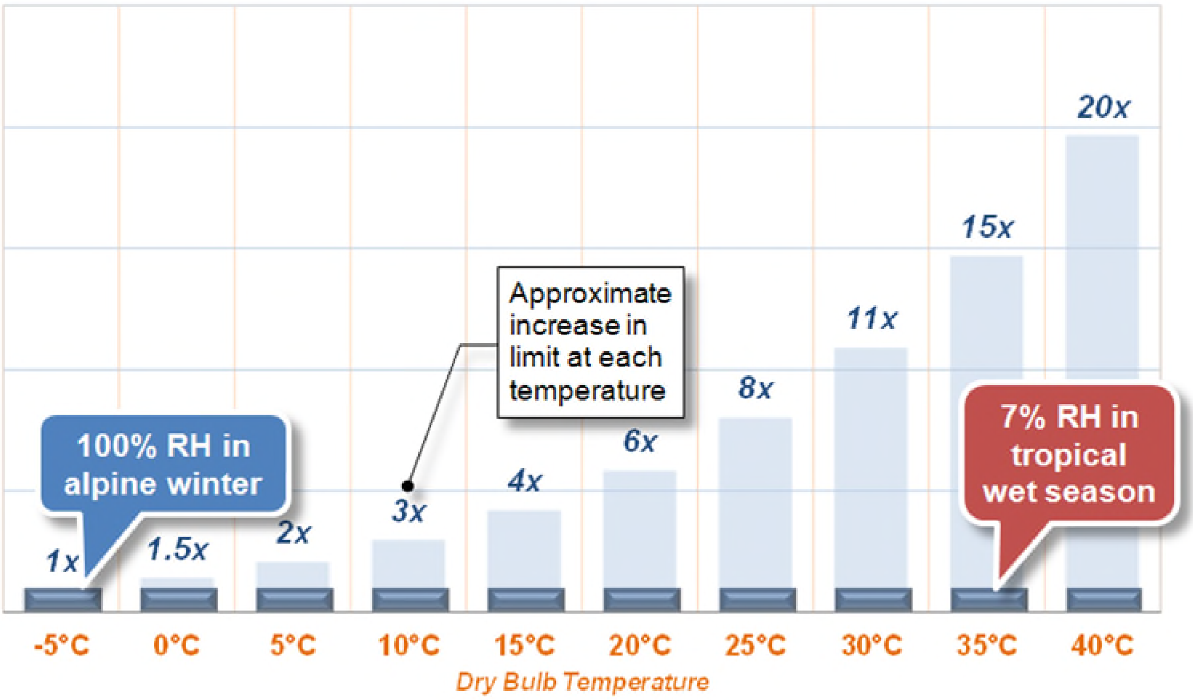
Two blue dotted lines across the chart illustrate how atmospheric water vapour levels vary across Australian climates. The lower line shows water vapour levels typical of the alpine winter; the upper line is for the tropical wet season. The intersection of each line with the dew point curve marks the dew point temperature in each case. There is so little vapour present in the cold alpine climate that the temperature must fall to nearly -5°C for the vapour to form frost. In the tropical atmosphere, with about eight times more water vapour, condensation can start around 25°C.

With the aid of a psychrometric chart, knowing the dew point temperature is enough to find how much water vapour is present and, of course, the temperature at which it will begin to condense on building surfaces. At dew point, the RH is always 100%.

3.2.5 Relative humidity (RH)

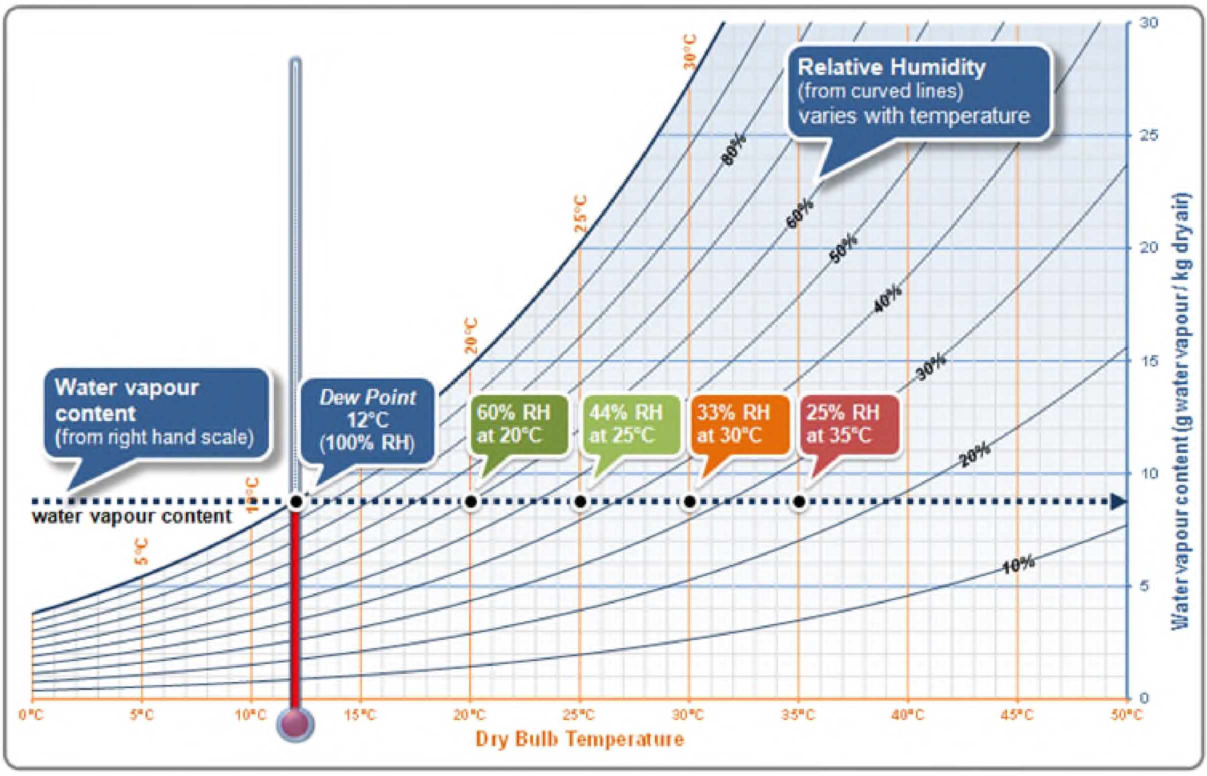
RH is probably the most frequently mentioned measure of the presence of water vapour in the atmosphere and also the most widely misunderstood. RH measures how much water vapour is present, compared to how much water vapour that temperature could hold. Figure 3.9 compares limits as temperatures rise with a small, fixed amount of water vapour. The fixed amount represents 100% RH in an alpine temperature but smaller and smaller percentages at warmer temperatures.

Figure 3.9 Approximate increases in water vapour limits rising with temperature
Note: When the amount of water vapour is fixed, the RH falls as the temperature rises



Changes in RH as temperatures rise or fall are indicated on a standard psychrometric chart by curved lines of the sort shown in Figure 3.10. This version of the chart uses a similar temperature range along the horizontal axis as the standard chart and the right-hand vertical axis measures the water vapour content of the atmosphere, in grams of water vapour per kilogram of dry air.

Figure 3.10 Water vapour content and RH on the psychrometric chart

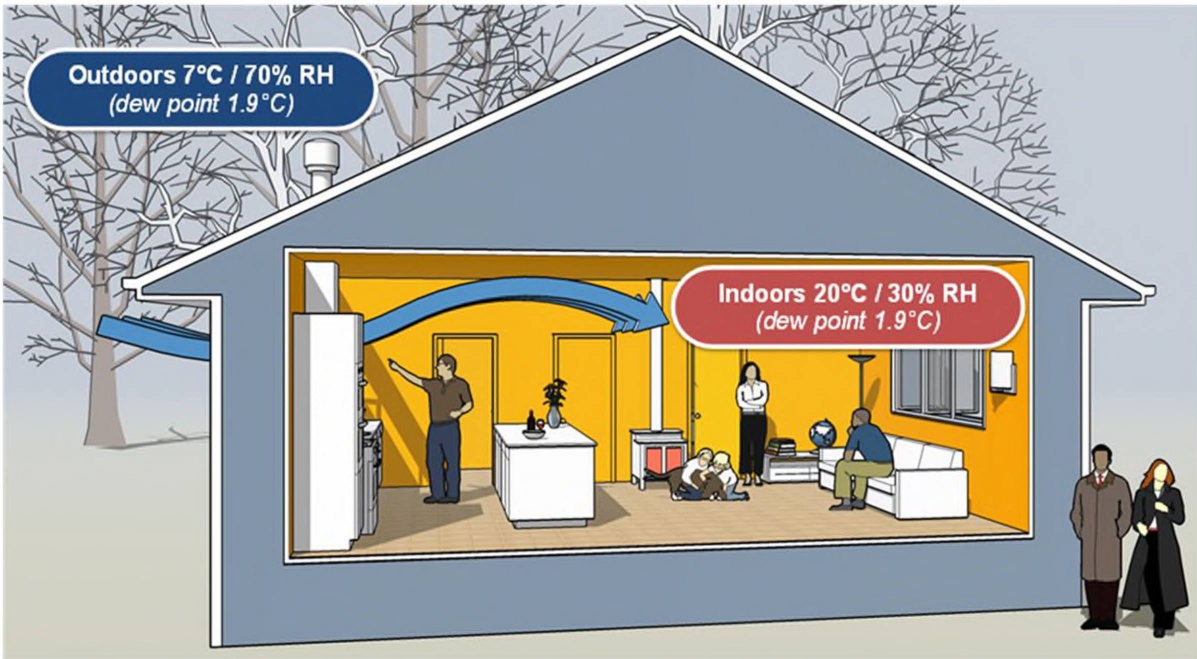


To illustrate the difference between the water vapour content and RH, a dotted line runs horizontally across the chart from the 12°C point on the dew point curve. Where the line meets the right-hand axis marks the water vapour content at that dew point. Points marked along the same dotted line highlight temperatures from 20°C to 35°C, in five-degree steps. By the time the temperature has risen from 12°C to 20°C, the RH has fallen from 100% (its dew point) to 60%. At 35°C, the RH has declined to 25% although the amount of water vapour in the atmosphere has not changed at all.

Unlike a dew point temperature, a RH percentage does not identify how much water vapour is present unless a temperature and pressure is also specified. 100% RH, which triggers condensation, can occur at any combination of temperature and water vapour level along the curved dew point line of the psychrometric chart. This means that environments can have high RH at low temperatures even if the water vapour content is low. Similarly, high RH can fall away as temperature rises.

Moving from the psychrometric chart to a building-related example, Figure 3.11 shows RH in outdoor air decreasing in a heated interior. Water vapour introduced from outdoor air is heated from 7°C to 20°C, lowering its RH from 70% outdoors to 30% indoors. The water vapour content at the dew point of 1.9°C remains the same indoors and out.

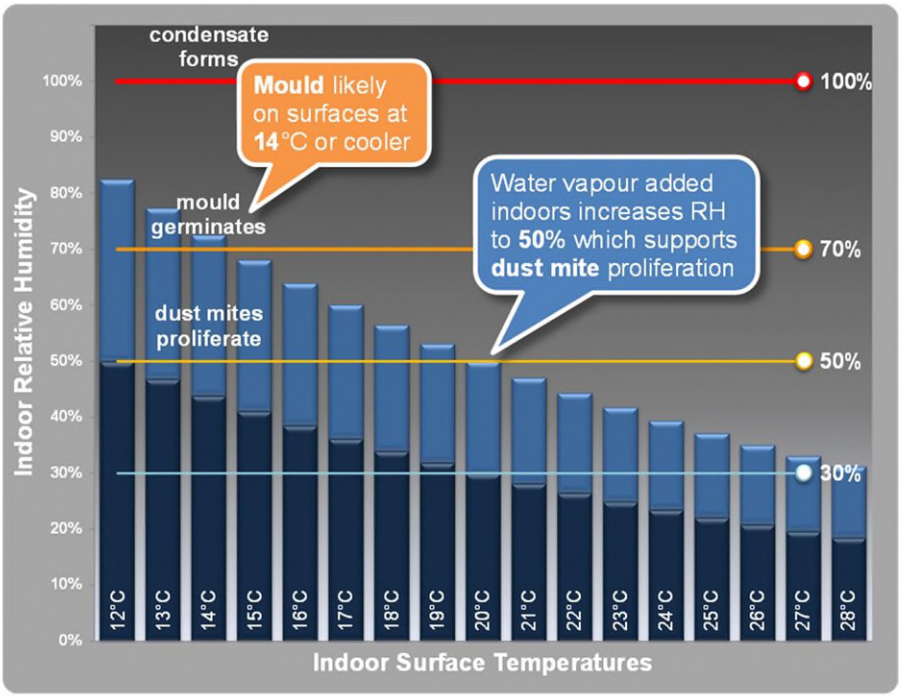
Figure 3.11 Warmer indoor temperature lowering RH of outdoor air from outdoors



In reality, outdoor air is not the only source of water vapour that will influence the RH indoors. All occupied buildings have their own internal sources of water vapour due, in part, to the breathing of the occupants and housekeeping. How much of the added water vapour accumulates inside the building will depend also on the rate of ventilation and or extraction systems.

A family of four could easily generate between 7 and 22 kg of water vapour per day. Figure 3.12 shows how extra water vapour, near the higher end of the range, could affect the 30% indoor RH at 20°C indicated in Figure 3.11. Even for a well-ventilated house, the RH at 20°C would rise to 50%, high enough to support rapid expansion of dust mite populations and their attendant health risks. At lower temperatures, which might occur when heating is turned off overnight, RH rises further and mould germination becomes possible at 14°C.

Figure 3.12 Warmer indoor temperature lowering RH of outdoor air from outdoors



The psychrometric chart in Figure 3.10 illustrates RH falling as temperatures increase but the risks for buildings stem from the rising RH which develops as temperatures fall. The temperature fall can be due to a cold external environment or cooling in an air-conditioned interior. As suggested by Figure 3.12, unwelcome effects can emerge before RH reaches 100% and the dew point when condensation begins.

3.2.6 Problems with relative humidity

RH can be too low as well as too high. Low RH can cause drying of the eyes, skin and mucosal membranes and contribute to dehydration and fatigue. These are symptoms which travellers might associate with passenger aircraft cabins, where RH is usually not much more than 10%. Simple measures of human comfort often suggest 30% RH as a lower limit and 60% as an upper limit (without mentioning a matching temperature range). Higher RH can interfere with natural cooling of the skin by evaporation of perspiration and lead to a familiar “sticky” feeling, as well as increase mould and fungus growth. Inside the 30-60% band suggested for human comfort, other creatures also feel at home such as house dust mites that release allergens.

In colder climates, mould can grow on room surfaces where they are cooled below the room temperature by heat loss to the outside. This can occur where insulation has too little thermal resistance for the severity of the climate or is locally interrupted by framing. Corners of walls, window and door openings are particularly susceptible because they are often constructed with multiple framing members, have limited space for insulation and air leaks through the external cladding is more likely. Windows may show problems first as they often have the coldest surfaces in a room and respond quickly to falling temperature (Figure 3.13).There is also the potential for mould growth in interstitial spaces and roof spaces.

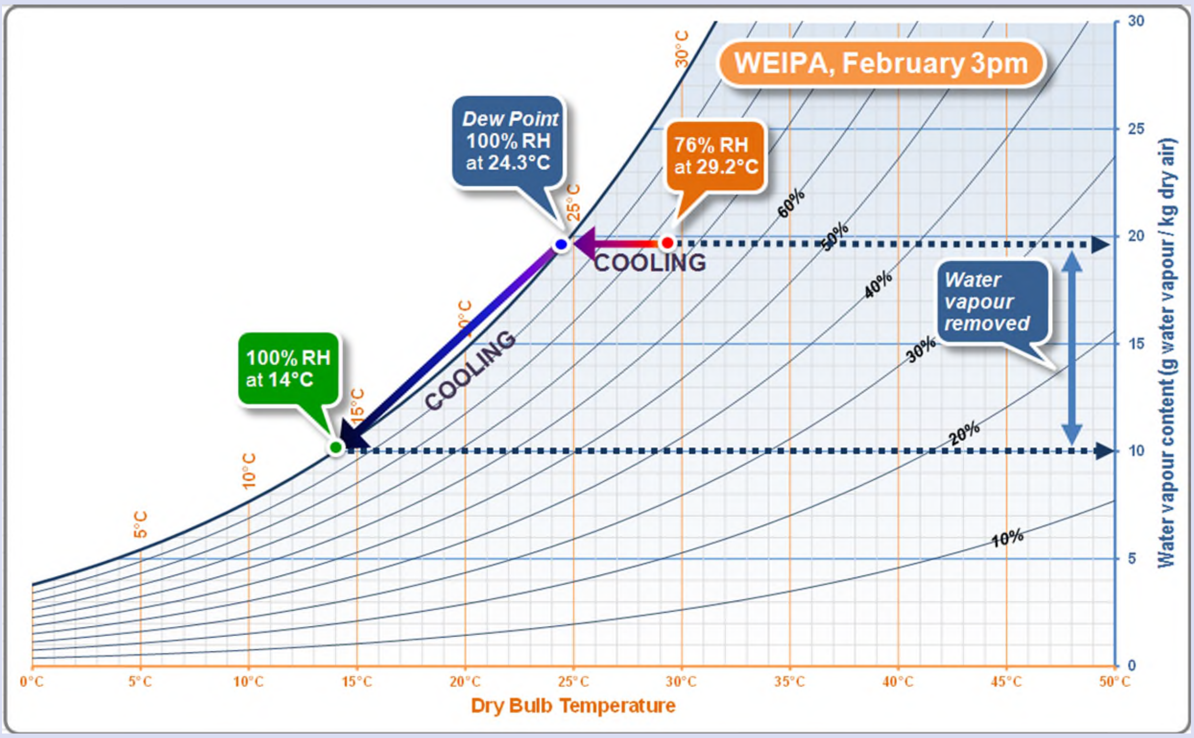
Figure 3.13 Surface temperatures of glazing in interior heated to 20°C (outdoors 0°C)

In warmer climates or seasons, when refrigerative air conditioning is used, initial cooling will increase the RH in the supply air stream. Cooling below the dew point temperature of the outdoor air will cause condensation and lower the water vapour content of the air, although the RH will remain at 100%. Cooling and removal of water vapour by condensation needs to continue to a point where mixing the supply air with indoor air will result in a RH below the 70% needed for mould growth.

Example

During February in Weipa, the mean outdoor air temperature is 29.2°C and the mean dew point is 24.3°C, indicating a RH of 76% (using the mean 3pm data). If this outside air is cooled to 25°C (with the temperature moving leftwards across the psychrometric chart below), RH rises to 96%. Cooled slightly further, it will reach its dew point and water vapour will begin to condense.

Figure 3.14 Psychrometric chart detailing the example of Weipa in February



Cooling to any lower temperature will unavoidably remove water vapour by condensation and lower the water vapour content in the atmosphere. Energy will be used both to reduce the temperature of the air and to remove the heat (latent heat of condensation) released by the condensing water vapour. The RH at the lower temperature will always be 100% but the water vapour content (on the right-hand scale) will have fallen significantly. Mixing the resulting cooled and dehumidified air with warm indoor air will lower the RH of the water vapour it contains.

Note: Artificial cooling in this climate is likely to include dehumidification limiting indoor surface risk. External layers of the building fabric in hot humid climates therefore become prone to condensation if cooling thermostats are set too low.

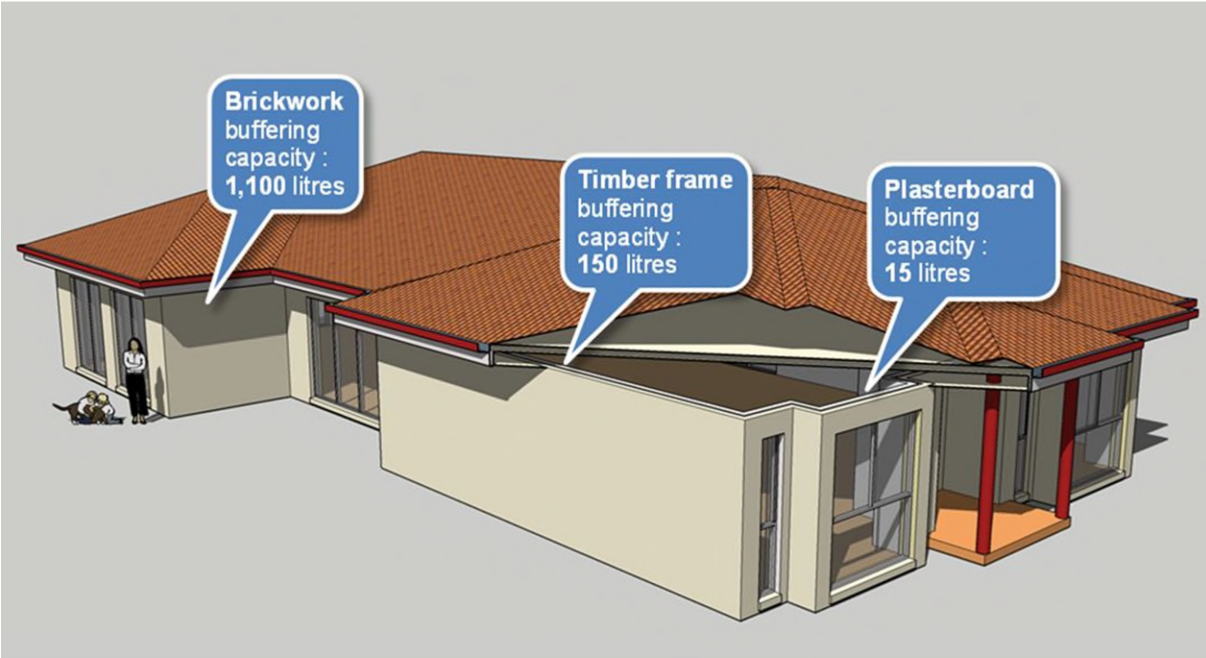
3.2.7 Material responses to relative humidity

There are many building materials commonly said to absorb water. Building science discussions make a distinction between adsorption and absorption. Some suggest that adsorption is a fourth state of water, along with ice, liquid water and water vapour. Adsorbed water is, in effect, water vapour whose isolated molecules have become attached to the microscopic surfaces of porous materials without clumping or clustering into liquid water. The materials which attract and capture water vapour molecules are considered hygroscopic. (“Hygro”, instead of “hydro”, indicates that water vapour is involved rather than liquid water.)

When a hygroscopic material has adsorbed all the water vapour it can, it is still able to take in liquid water by capillary suction (wicking) or absorption and store it in the pores and cracks of the material. Wood, for example, can increase its moisture content up to about 25 or 30% at 98% RH simply by capturing (adsorbing) water vapour molecules from the atmosphere onto its pore walls. Wood which is fully saturated by liquid water can hold two to four times that amount of moisture in its pore spaces.

Hygroscopic materials respond to RH rather than to absolute water vapour content. They take in more water vapour when RH is high and release it when RH falls. Since RH rises as temperatures go down, cooler temperatures will increase water vapour capture and storage in hygroscopic materials. This response to RH can provide a useful hygric buffer or safety margin when water vapour levels are rising or temperature is falling. Figure 3.15 shows the approximate temporary storage capacity of the three main components of the external walls of a modest brick veneer home.

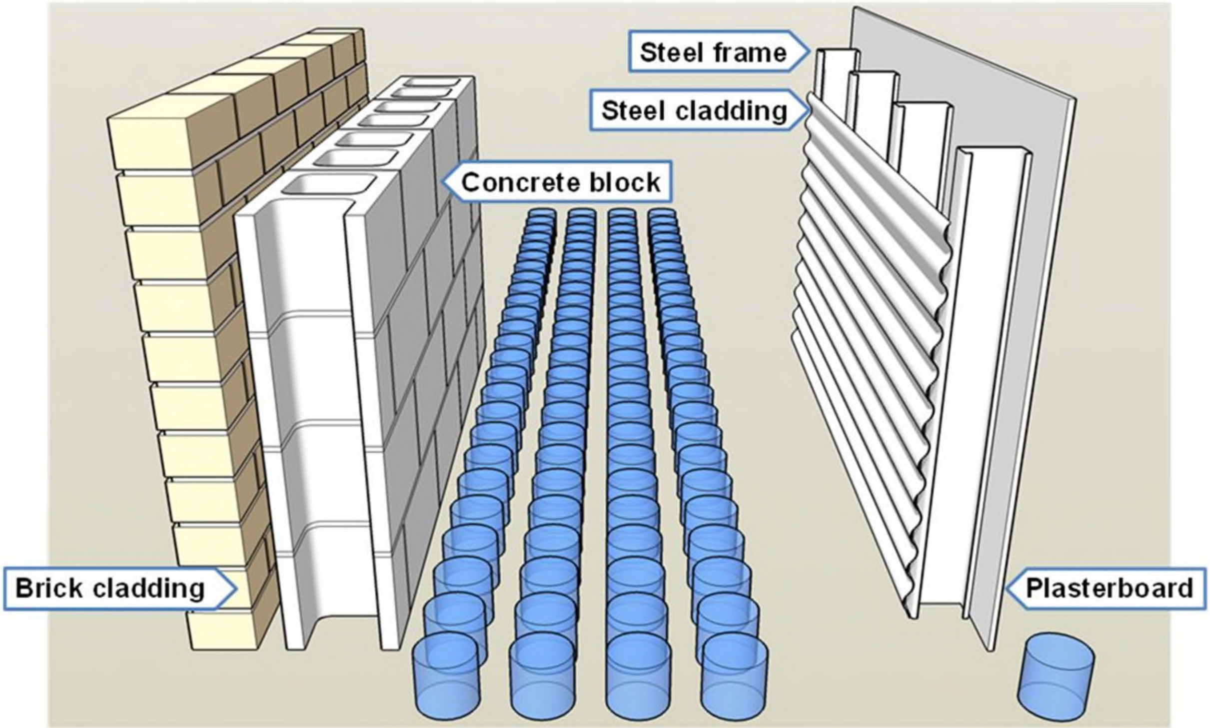
Figure 3.15 Safe buffering capacity of materials in the external walls of a 185 m² brick veneer home (Based on an adaptation of Lstiburek 2002)



The interior plasterboard lining, in first contact with this airborne water vapour, can take up some of it by adsorption and help to stabilise RH at less problematic levels. The timber frame would increase the buffering capacity of the wall assembly more than ten times. Brick veneer for the external cladding increases it by more than 80 times (Salonvarra et al. 2007).

Noting that the capacity for a building material to adsorb and store moisture is dependant not only on its material properties but also the vapour pressure and temperature. The beneficial storage and buffering capacities of lightweight and high mass walls are compared in Figure 3.16.

Figure 3.16 Comparative safe moisture storage capacity of masonry and light framed walls

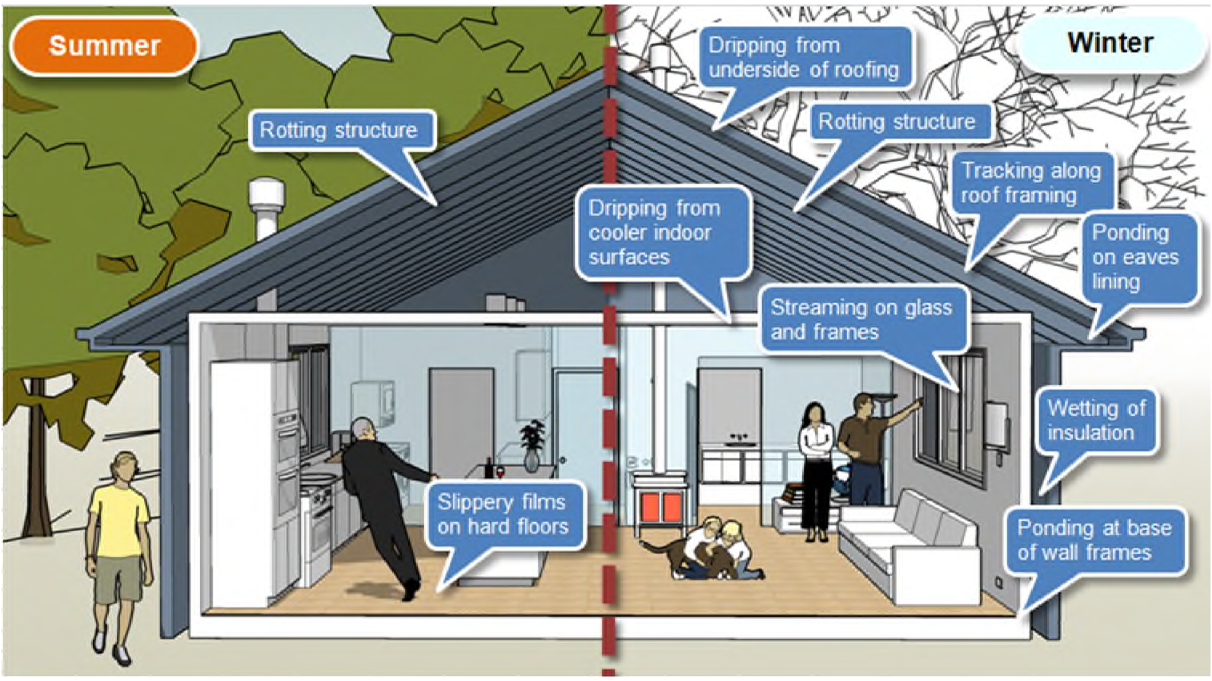


Relying on the hygric capacity of the building envelope construction is not a panacea for avoiding problems with water vapour. Some of the capacity will be needed to deal with periodic wetting by rain, surface water or rising groundwater, and some for construction moisture in the building fabric itself (e.g. water in concrete slabs or steam cured concrete blocks).

North American and European experience has revealed potential difficulties with exterior claddings with high water storage capacity. In this context, they are termed reservoir claddings. Saturated after heavy rainfall and heated by the sun, they release water vapour which will migrate towards a cool air-conditioned interior.

Once RH of water vapour at a surface has reached 100% and dew point, it will revert to liquid water or frost. Figure 3.17 illustrates a number of risks that may follow.

Figure 3.17 Some risks from condensation in the occupied and interstitial space of a building



Liquid water responds to gravity to accumulate, run, drip and pond, possibly causing nuisance or damage in places away from the first point of condensation. When water appears where it is not wanted in a building, it is often taken as evidence of a leak rather than condensation, and a search for the cause begins in the wrong places. One strong indication that a phantom leak could be at work is when water emerges in the absence of significant rainfall.

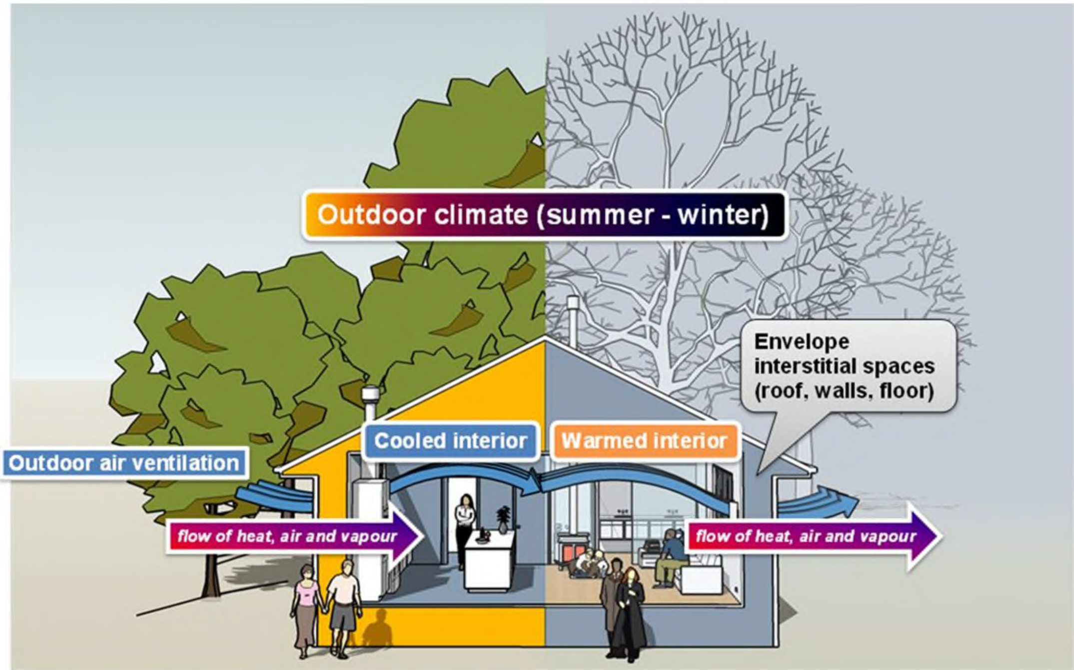
3.3 Climate

This section covers the concepts related to climate classifications and their use in assessing condensation risk, outdoor condensation potential across Australia, assessing local outdoor climate, indoor climate and a basic assessment of the impact of indoor water vapour loads.

3.3.1 Climate classifications

When dealing with condensation, there are at least two climates to consider: one that the weather constructs outdoors and the other, the one indoors created accidentally or by design. Indoor conditions will depend on the activities of the occupants and their attempts to maintain comfort as the seasons change outdoors. The outdoor and the indoor systems are unavoidably linked by the need to provide outdoor air to the indoors and to flush stale inside air to the outside. The exchange of heat, air and water vapour through the apparently solid surfaces that separate the indoor and outdoor climates (Figure 3.18) will set conditions for what happens in the interstitial spaces of the building envelope. This chapter deals firstly with the climate outdoors and then with the range of indoor conditions which can influence condensation risk.

Figure 3.18 Outdoor and indoor climates



The notion of climate is an attempt to discern some order in the vagaries of the weather. Although the characterisation of a climate does not settle the question of whether to take an umbrella tomorrow, it can indicate broadly what to expect from season to season and from month to month in a given place. There are many different systems of climate classification in use for different purposes and some of them are very complex.

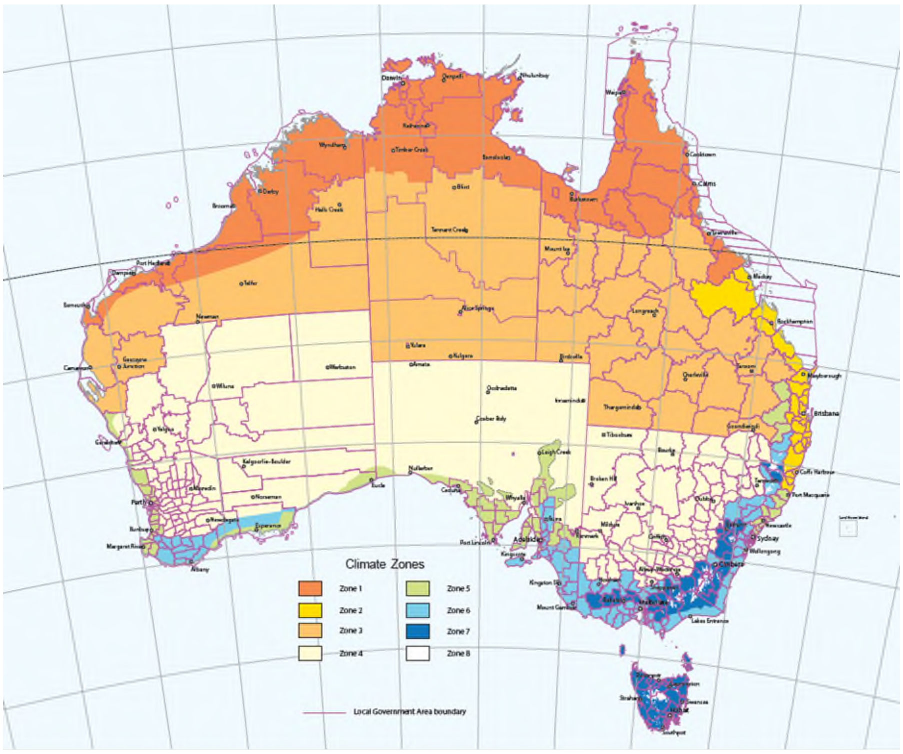
Climate classification systems for building design usually focus on environmental factors which affect human comfort. With this approach, as few as four climate categories can be enough to set fundamental thermal design strategies (Szokolay 1995). The four basic climate types are:

- **Cold climates –** where humans feel too cold under outdoor conditions for all or most of the year. These climates offer too little heat or encourage too much heat loss.
- **Temperate climates –** where 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. Large falls in overnight temperatures also relieve hot daytime conditions.
- **Warm humid climates** – 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.

These four categories, in reverse order, form the basis of the eight climate zones used by the NCC energy efficiency provisions (Figure 3.19).

Figure 3.19 NCC climate zones for thermal design (i.e. energy efficiency) (Source: Schedule 1 of the NCC)



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The eight NCC climate zones for energy efficiency involve subdivisions of the basic types of climate to reflect differences in typical temperatures and consequent insulation requirements.

Their numbering begins with the warm humid type which is divided into climate zone 1 (hot summer) and climate zone 2 (mild summer). The hot dry climate type has two variants, in climate zone 3 (warm winter) and climate zone 4 (cool winter). The temperate climate type forms the basis for zones 5, 6 and 7 (which have warm, mild and cool temperate designations). The cold climate type is represented in the NCC designations only by climate zone 8.

Developed with an emphasis on defining the desirable thermal characteristics of building envelopes, the eight NCC climate zones are not reliable indicators of condensation risk in buildings. Figure 3.20 illustrates the likelihood of outdoor condensation (as dew or mist) overnight in 12 locations from climate zone 5, which is considered a "warm temperate" climate. Even a glance at the colouring of the table cells suggests considerable differences between locations in the same NCC climate zone (the text below the figures explains the colouring of the table cells).

Figure 3.20 Comparative outdoor overnight condensation potential in NCC climate zone 5 (Blue column borders highlight winter months (June, July and August))

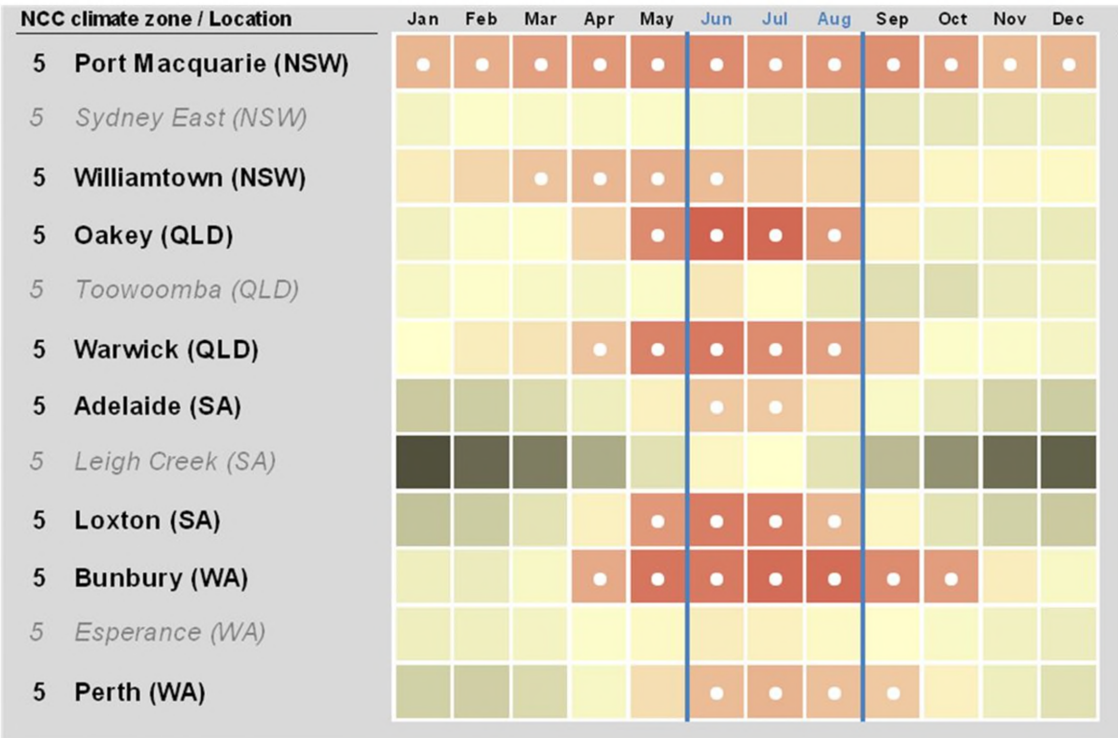


Figure 3.20 uses BOM data to compare the mean minimum temperature in each month with the average dew point temperature, based on 9am and 3pm data, for that month. Where the mean minimum temperature falls on or below the average dew point, the table

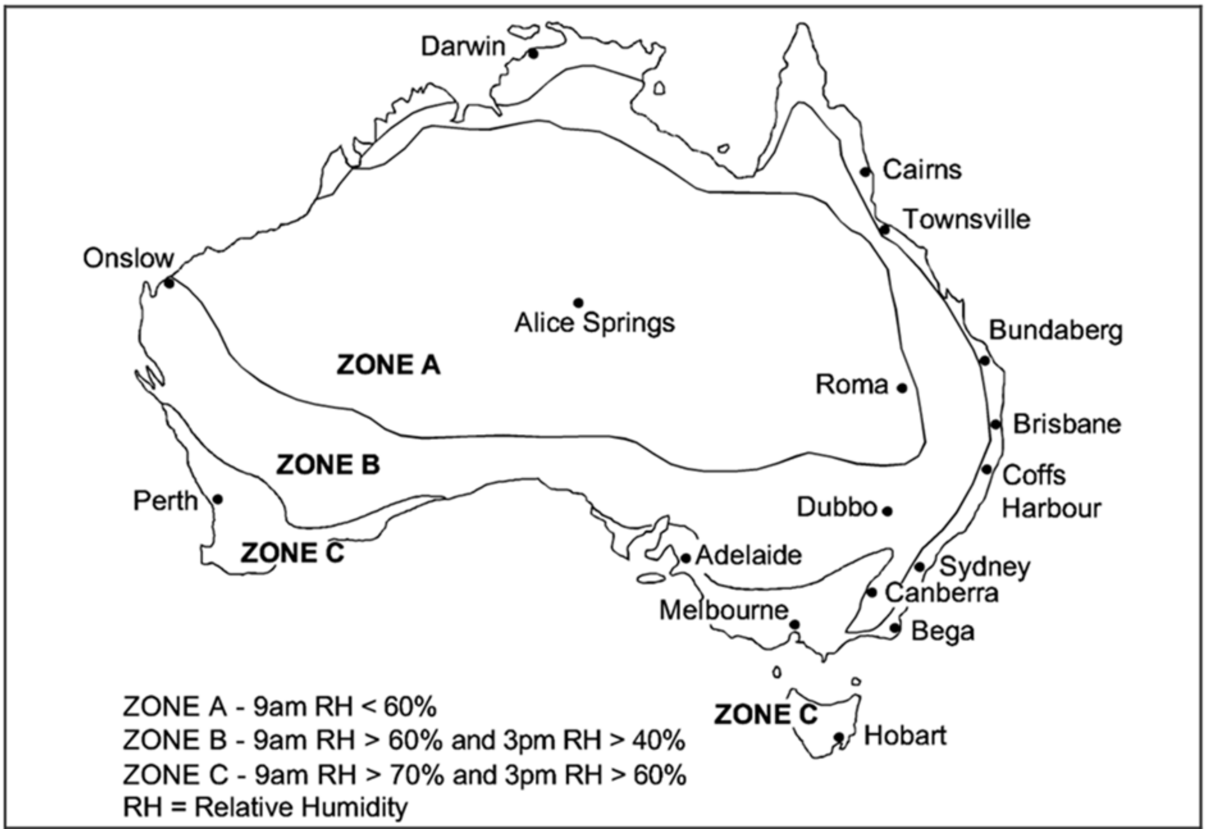
cell contains a white dot on a red-brown background. The intensity of the red-brown colouring indicates how far the overnight temperature falls below dew point. Months without dots have minimum night time temperatures above dew point but any red-brown colouring indicates a close approach to the dew point. The further the overnight minimum temperature remains above dew point, the darker is any grey-green colouring in each month.

Overnight outdoor condensation potential persists for 12 months in Port Macquarie (NSW) but none is indicated for Sydney East (NSW), Toowoomba (Qld), Leigh Creek (SA) or Esperance (WA), under mean monthly conditions. Figure 3.20 also highlights that conditions favouring outdoor condensation are not necessarily confined to the colder winter months (June, July and August).

As stated, the data above is based on mean or average monthly temperatures. However, in practice, these values may vary significantly from the daily maximum and minimum temperatures experienced in a location and do not provide a magnitude of the duration of these temperatures, factors which may also need to be considered when determining the risk of condensation.

The NCC also uses a second climatic classification system in describing DTS Provisions for sub-floor ventilation. Figure F1D8 in NCC Volume One and Figure 6.2.1a in the Housing Provisions (referenced in NCC Volume Two), identify three “climatic zones” based on seasonal RH, designated as zones A, B and C (Figure 3.21).

Figure 3.21 Climatic zones based on RH for sub-floor ventilation
(Source: Figure F1D8 in NCC Volume One and Figure 6.2.1a in the Housing Provisions)



Note: The season with the highest relative humidity is used. Generally this will be July for southern Australia and January for northern Australia.

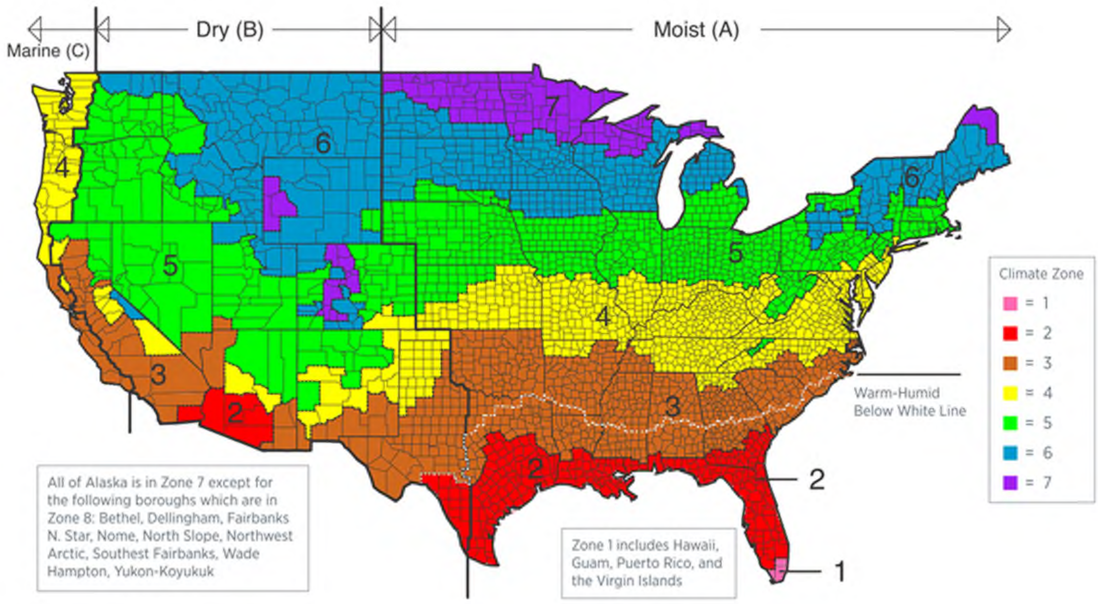
Comparing the differing potential for overnight outdoor condensation shown in Figure 3.20 for Sydney, Adelaide and Perth, which are all in climatic zone C of Figure 3.21, suggests that the three-zone classification system does not identify variations in condensation potential well enough to be used outside of its current NCC context. If the eight NCC climate zones for energy efficiency and the three climatic zones for sub-floor ventilation arrangements cannot categorise Australian climates finely enough for condensation risk assessment, attention might be drawn to climate classifications used in other countries.

3.3.2 Climate classification for assessing condensation risk

Demonstrated condensation problems in more severe environments have spurred the classification of climates using both thermal and moisture-based criteria. In the US, for example, the International Energy Conservation Code (IECC) identifies eight temperature-oriented zones which can be sub-divided by three moisture designations. This allows as many as 24 classifications of temperature and moisture conditions. However, as is the case with the NCC climate zones, these climate classifications often follow jurisdictional boundaries, which may not be truly reflective of the climate of that place.

Figure 3.22 shows the application of the system, county by county, to the contiguous US (below the Canadian border). Only zones 1 to 7 are illustrated because the coldest zone 8 is confined to certain boroughs of Alaska. The boundaries of the moisture categories (moist, dry and marine) are marked by heavier lines and labelled above the map. A combination of thermal zone numbers and moisture category labels can be used to indicate the conditions affecting thermal design and condensation risk in particular counties.

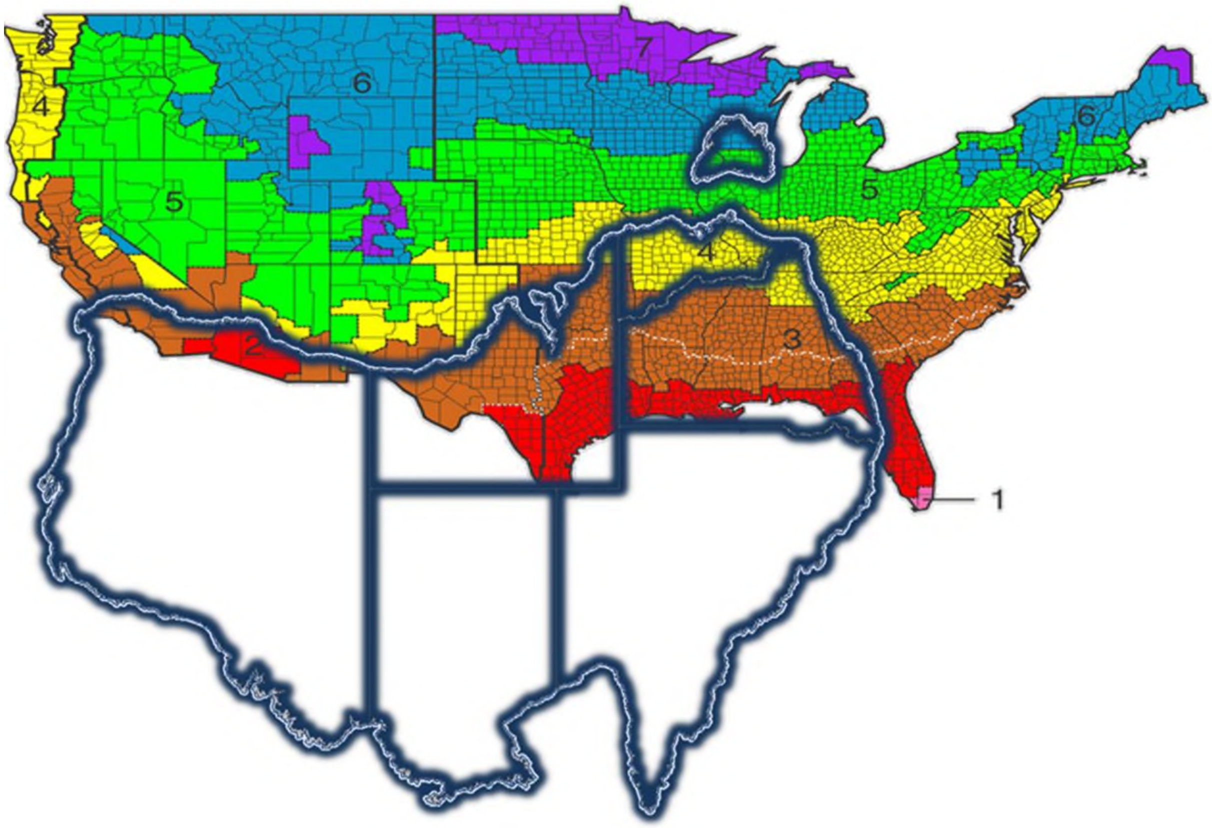
Figure 3.22 IECC climate zone map (Source: Building America 2010)



The prospect of being able to apply the very extensive US research and experience on condensation management provides an incentive to fit Australian locations into the IECC climate classifications. However, any attempt at alignment quickly reveals significant mismatching on one criterion or another. Many US locations, for example, have a mean annual outdoor temperature substantially cooler than the average outdoor dew point temperature in one or more months (Lstiburek 2011). This situation is rare in Australian climates. A basic benchmark to note, however, is that one of Australia's coldest climates, Thredbo, fits into the IECC cold climate category (zone 6 in Figure 3.22) by having an annual heating requirement of about 4,900 Heating Degree Days (HDD to base 18°C). The qualifying range for IECC zone 6 is 3,000 to 5,000 HDD.

This mismatch is reinforced when the Australian land mass is overlaid on the contiguous US at equivalent latitudes, as shown in Figure 3.23. Although latitude alone does not account for climatic similarities, the true-to-scale comparison of the Australian and US shows that the maps overlap mainly in regions designated in the US as hot or mixed climates (humid on the east and dry on the west). Australia's greater latitude span (33° compared to 25°) means that its North-South dimension is about 900 km greater than for the US and its closer proximity to the equator (10° rather than 25°) tends to extend the meaning of the terms "hot" and "humid". Whilst it is useful to benchmark Australian climatic conditions with other regions of the globe, care should be exercised when applying the principal findings of condensation solutions in practice between different regions.

Figure 3.23 Australian land mass overlaid on the contiguous US at equivalent latitudes (The side-to-side placement provides an approximate alignment of moist and dry regions.)



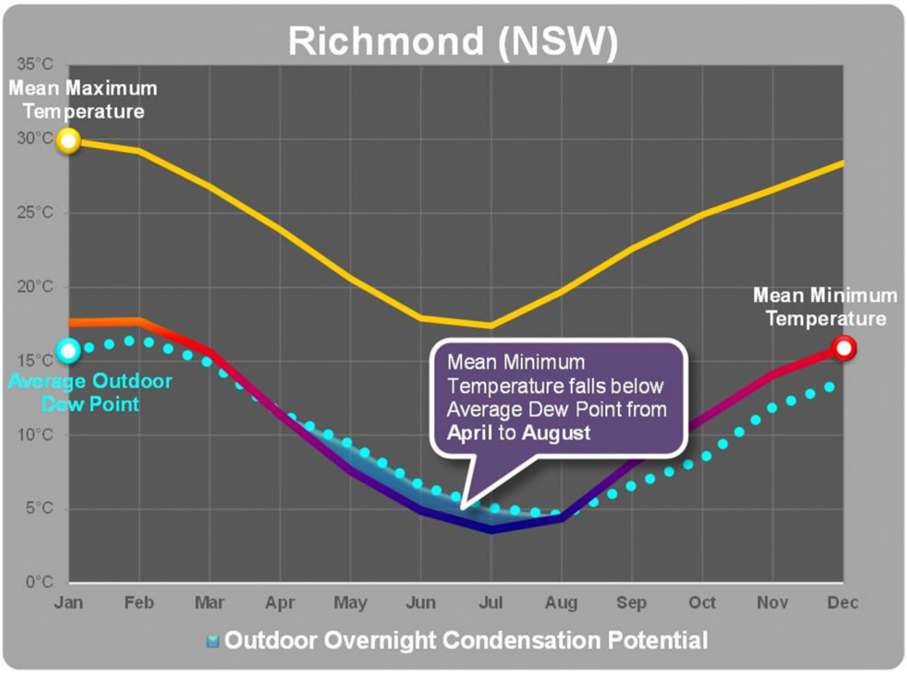
In addition to differences in outdoor climates, systematic classification of climates also needs to be matched by consensus on how indoor and outdoor conditions are to be applied in risk calculation methods. Current calculation methods and software tools are very sensitive to the assumed environmental conditions. For the US, ANSI/ASHRAE Standard 160:2016 offers “Criteria for moisture-control design analysis in buildings”, to provide a consistent framework for design assumptions or assumed loads. Noting the lack of similar information for Australian conditions, Dr Richard Aynsley (2012a), Building

Energetics Pty Ltd, suggests that “Australia needs a standard on moisture control in buildings that reflects the huge span of latitude of the country. Without an Australian standard for assessing condensation risk, there is no consensus on what are appropriate input data, hygrothermal analysis methods, or evaluation of results”.

3.3.3 Outdoor condensation potential

Without an established consensus, Australian building practitioners may still find useful information in local resources. Figure 3.24, for example, uses some of the information available in monthly climate statistics provided online by the BOM to highlight the potential for condensation under outdoor conditions. The necessary information is available for numerous Australian locations.

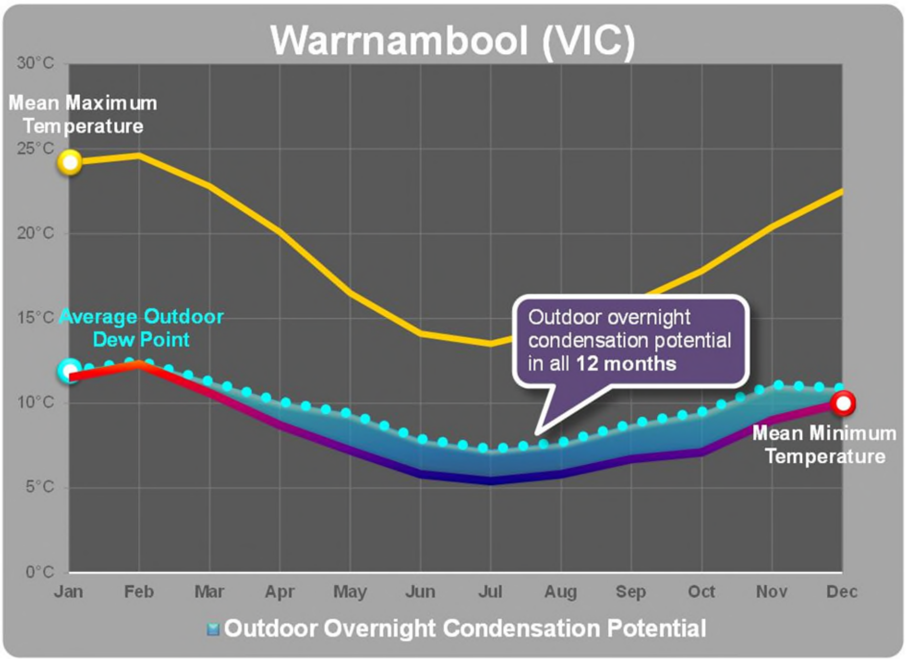
Figure 3.24 Comparison of monthly mean minimum temperatures and average dew points (outdoor overnight condensation potential)



The BOM statistics provide (among other details) mean minimum and maximum temperatures for each month, averaged over the number of years available for each weather station location. The record also contains monthly mean dew point temperatures for 9am and 3pm, which indicate the water vapour content of the atmosphere at those times. The charts in Figure 3.24 and Figure 3.25 compare the average of the dew point values (dotted blue curve) with the mean minimum temperature in each month. When the mean minimum temperature (red/purple curve) falls below the dew point, condensation can occur, as highlighted by the blue filled area between the curves.

As Figure 3.25 shows, the potential need not be limited to the colder months of the year. In some locations, the necessary combinations of temperature and water vapour levels can occur in any season. In both charts, the yellow mean maximum temperature curve offers some context for the daytime conditions likely to follow overnight condensation events. It is typical of many Australian locations that conditions triggering condensation will be followed by warmer daytime conditions that can assist drying. As a result, the overnight condensation flagged by these comparisons may be a temporary event with little lasting effect. This possibility is discussed further in Section 3.3.6, where the effects of likely indoor water vapour loads for homes are also considered.

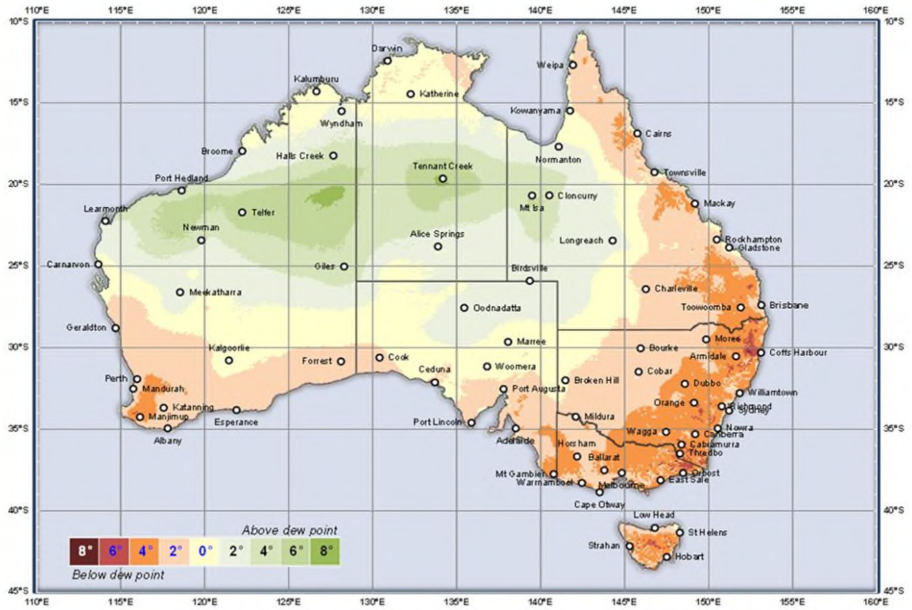
Figure 3.25 Outdoor overnight condensation potential spanning all 12 months



The comparisons illustrated in Figure 3.24 and Figure 3.25 can identify the month with the greatest scope for outdoor night time condensation and how many months could be affected in each year, under average conditions. Applying this test to 160 specific BOM locations shows that 95 of them, drawn from all NCC climate zones, have potential for outdoor overnight condensation in at least one month. It is important to remember that this is a rudimentary evaluation of potentially transient effects and it does not take into account the indoor environment and building fabric arrangements needed to cause problems in the occupied spaces of a building or in the interstitial layers and spaces of its envelope. Nevertheless, identifying regions with a propensity for outdoor condensation due only to climatic factors may offer a preliminary basis for characterising the contribution of local climate to condensation risk in various locations across the country.

To provide a nationwide comparison, the ABCB has used a gridded data set generated by BOM to calculate comparisons for locations across Australia and to assemble the results into a map of comparative outdoor overnight condensation potential (See Figure 3.26 and Appendix D.1 for larger version). The map shows the approximate margin between the mean minimum temperature and the average dew point in the worst-case month for each part of the grid.

Figure 3.26 Exploratory map of comparative outdoor overnight condensation potential (For use with this handbook only. Further details and an enlarged version are provided in Appendix D).



The first purpose of the map is to alert practitioners and building users to locations where outdoor dew point and temperature combinations warrant closer attention to design and behavioural factors which make condensation more likely. In those locations, the methods outlined in Sections 3.3.4 and 3.3.6 can provide a more detailed assessment of the outdoor climate, its influence on preferred indoor conditions and possible scope for persistent temperature and humidity conditions that might lead to troublesome condensation or elevated RH.

In assessing outdoor condensation potential, building project participants could consider the following steps (as a minimum):

- detailed analysis of the local climate (possibly using the method in Section 3.3.2 or a preferred alternative)
- evaluation of the likely worst case internal water vapour loads and air leakiness of the building envelope
- minimising rain exposure of envelope walls and lower storey roofs

- minimising perpetual shading of envelope walls and lower storey roofs
- selecting façade and roofing systems more robust against construction flaws, i.e. those with higher hydric capacity or that incorporate sufficient non-porous insulation
- using assemblies and materials in the building envelope with higher hygric capacity
- reducing the use of moisture sensitive materials
- analysing the layering of envelope insulation to keep potential condensing surfaces warm, and
- exhausting indoor water vapour sources directly to the outside (NCC requirement, refer section 2.3.2)
- enhancing ventilation arrangements that can dilute indoor water vapour levels (NCC requirement, refer section 2.3.2)
- employing building pressurisation through mechanical systems to limit unwanted water vapour migration towards cooler surfaces.

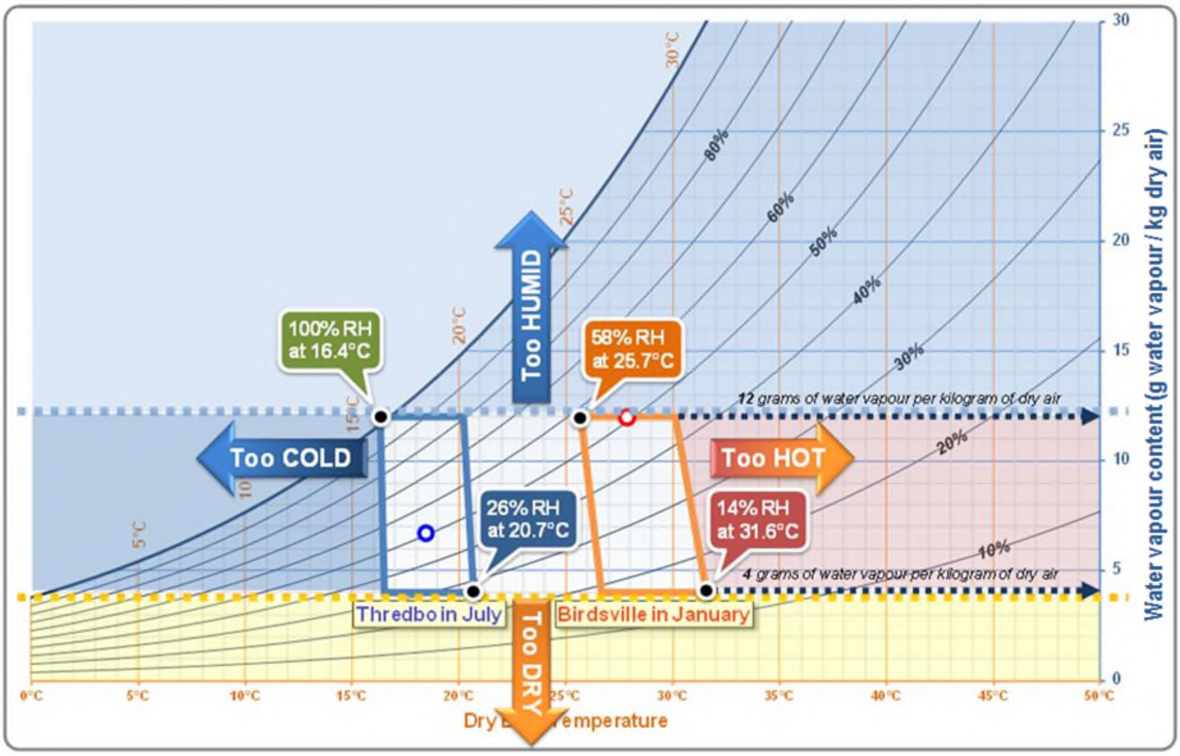
3.3.4 Assessing local outdoor climate

A more comprehensive view of the nature of the climate in any one place and how it can affect a building and its occupants' behaviour can be assembled using a psychrometric chart and the BOM climate statistics discussed in section 3.3.3. Szokolay (1995) explains how to plot typical human comfort limits for a chosen location onto the psychrometric chart and compare them with the average monthly temperature and humidity statistics reported for the location.

Figure 3.27 shows comfort limits calculated for a winter month in a cold climate and a summer month in a hot dry climate, based on the average outdoor temperatures for those months. The small portions of the chart marked out for each location represents the preferred indoor climate for people who are acclimatised to local conditions, lightly clothed and engaged in sedentary activities. These conditions are likely to suit residential buildings but not necessarily other types. The white centred dot, always on the 50% RH line, represents the point of thermal neutrality where most people feel neither hot nor cold.

The sloping sides of each comfort zone indicate acceptable temperature limits at various water vapour concentrations and the top and bottom represent the comfortable range of water vapour content (4 to 12 g/kg in all locations). Comfort zones for milder climates would fall to the right of the Thredbo example and to the left of the Birdsville zone. Comfort limits calculated for annual average temperatures, rather than monthly values, would also fall between the extremes.

Figure 3.27 Range of human comfort limits for Australian climates (outdoors)



Examining which of the curving RH lines pass through the two comfort zones provides some useful observations. The Birdsville case suggests that building occupants acclimatised to summer in a hot-dry climate may tolerate RH lower than 20% and up to about 60% (from bottom-right corner of the comfort zone up to top-left). People here would notice discomfort before RH reached levels likely to promote mould growth on building surfaces. By contrast, adaptation to the cold Thredbo winter climate allows RH approaching 100% to feel acceptable. In colder climates, problematic RH levels may develop without providing any sensory alert to occupants.

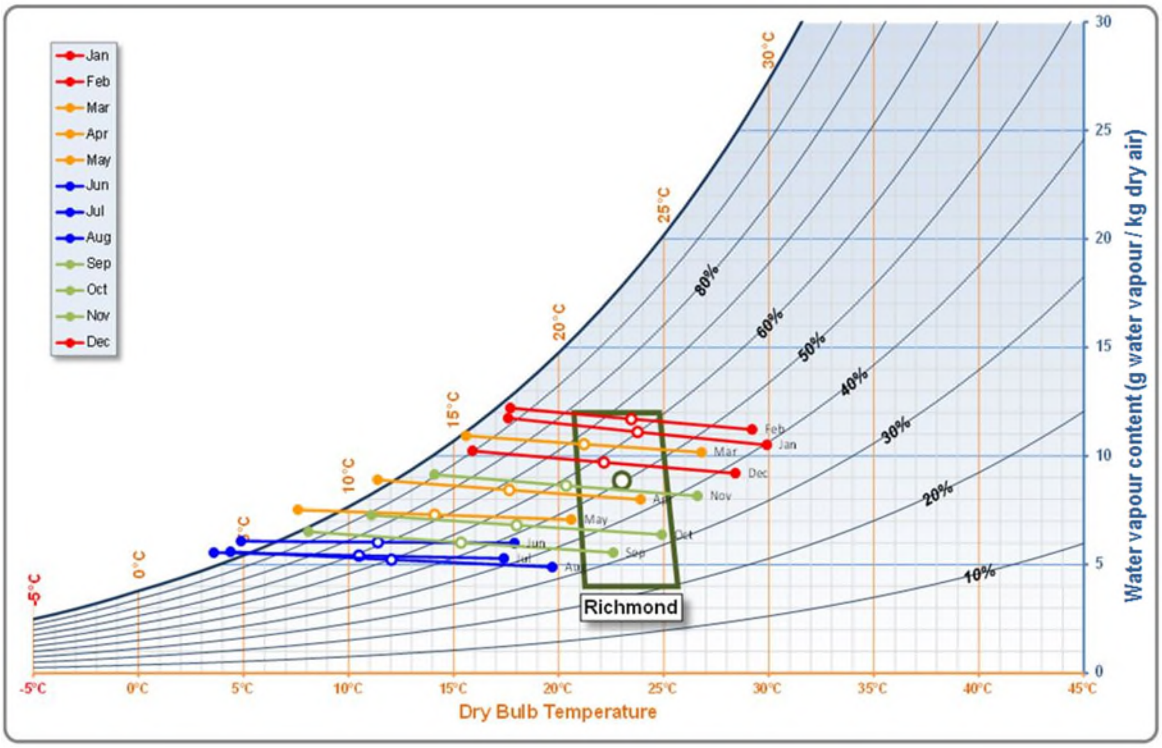
Outdoor climate data is added to the psychrometric chart, using twelve straight lines to represent average monthly conditions based on BOM data. In Figure 3.28, which has Richmond (NSW) as an example, the lines are red for summer months, orange for autumn, blue for winter and green for spring. Each monthly line connects two points on the chart. The points are defined by locating the:

(1) average (or mean) minimum temperature for the month and the mean dew point temperature at 9am (which, it is recognised, will not occur at the same time)

(2) mean maximum temperature and the 3pm dew point temperature.

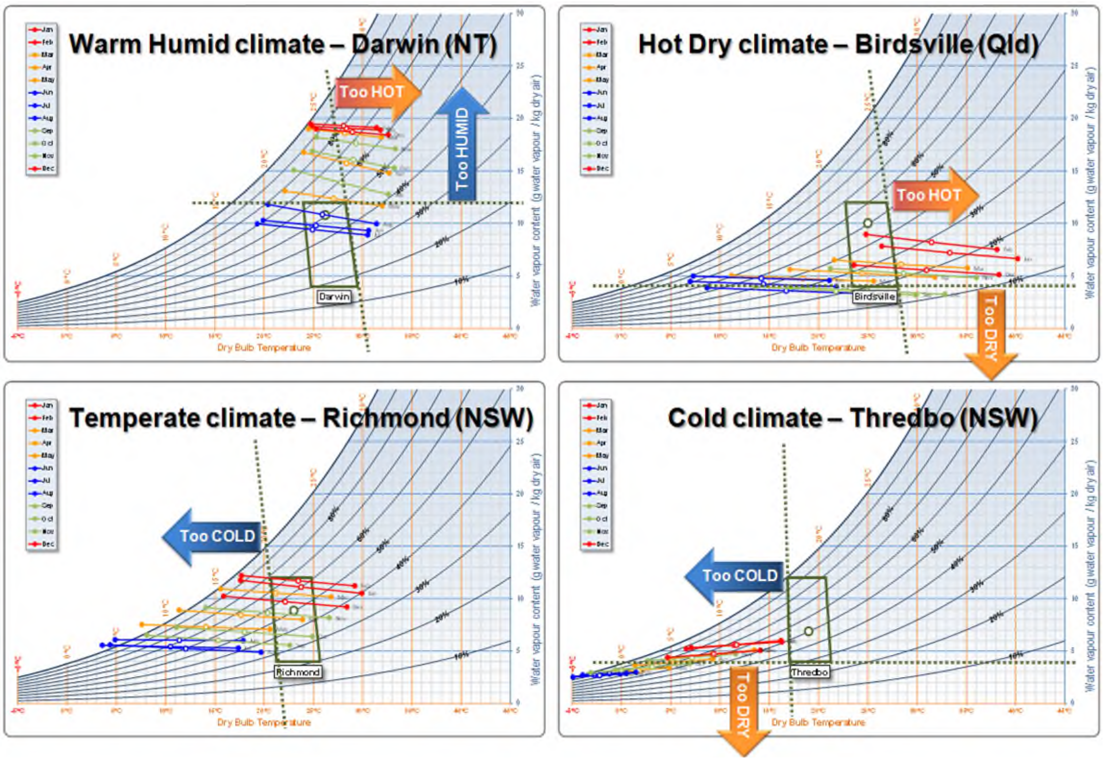
A midpoint on each line, with a white centre, shows the average dew point temperature for the month (read from the saturation curve) and the average temperature (read from the dry bulb temperature scale on the x axis).

Figure 3.28 Climate analysis on the psychrometric chart: Richmond (NSW) – mild temperate



The Richmond (NSW) example is typical of the temperate climate type. Winter minimum temperatures (left hand ends of the blue lines) in such climates may fall below zero but the mean temperatures in winter months (midpoints) remain above freezing. Summer maximum temperatures (right hand ends of the red lines) can exceed the comfortable limit (right side of the comfort zone) but the mean temperatures (midpoints) remain below it. Other implications of Figure 3.28 are examined further by comparing it with examples of the other three basic climate types (Figure 3.29).

Figure 3.29 Characteristics of the four basic climate types (enlarged versions are located in Appendix D)

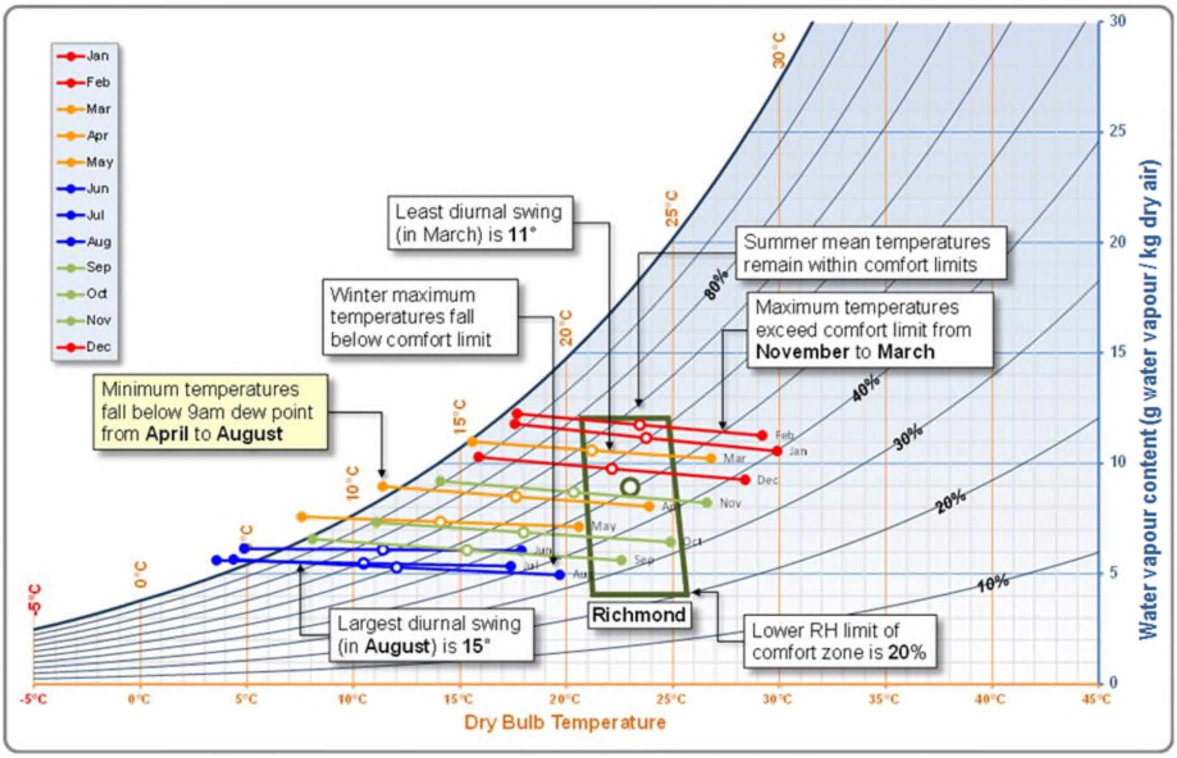


Distinct differences between the four climate types are quickly evident in Figure 3.29, where the placement, spacing, length and slope of the monthly lines are all significant. In considering what the charts suggest about the nature of the climate, and possible responses by building occupants seeking to remain comfortable, the key characteristics to look for are the:

- vertical placement of monthly temperature/humidity lines above and below the comfort zone (indicating months when humidity is uncomfortably high or too low)
- vertical separation of lines (indicating monthly/seasonal variations in humidity levels)
- slope of lines from left to right (indicating rising or falling humidity levels between mornings and afternoons)
- sideways extension of lines (left and right) of the comfort zone (indicating when temperatures will be cooler/warmer than preferred, likely to lead to heating/cooling)
- horizontal distance between end points of the lines (indicating day to night, or diurnal, temperature ranges, which may provide relief from high daytime temperatures or influence the potential for overnight condensation or daytime drying)
- RH at the right-hand end of monthly lines (indicating daytime drying potential when RH is low)
- horizontal spread of lines (indicating temperature variations between seasons).

Figure 3.30 returns to the Richmond (NSW) climate and highlights some of the temperature characteristics likely to influence heating and cooling choices, perceptions of uncomfortable RH levels and, notably, the possibility of overnight condensation under outdoor ambient conditions from April to August. While this is similar to the indications of risk in Figure 3.24, the overnight minimum temperature here is compared with the 9am dew point, rather than the average dew point.

Figure 3.30 Annotated climate analysis for Richmond (NSW) – mild temperate



This graphical approach has the advantage of assembling information about average outdoor conditions in all 12 months in a compact format. The same approach is extended in Section 3.3.6 to address the likely impact of water vapour levels in the indoor climate.

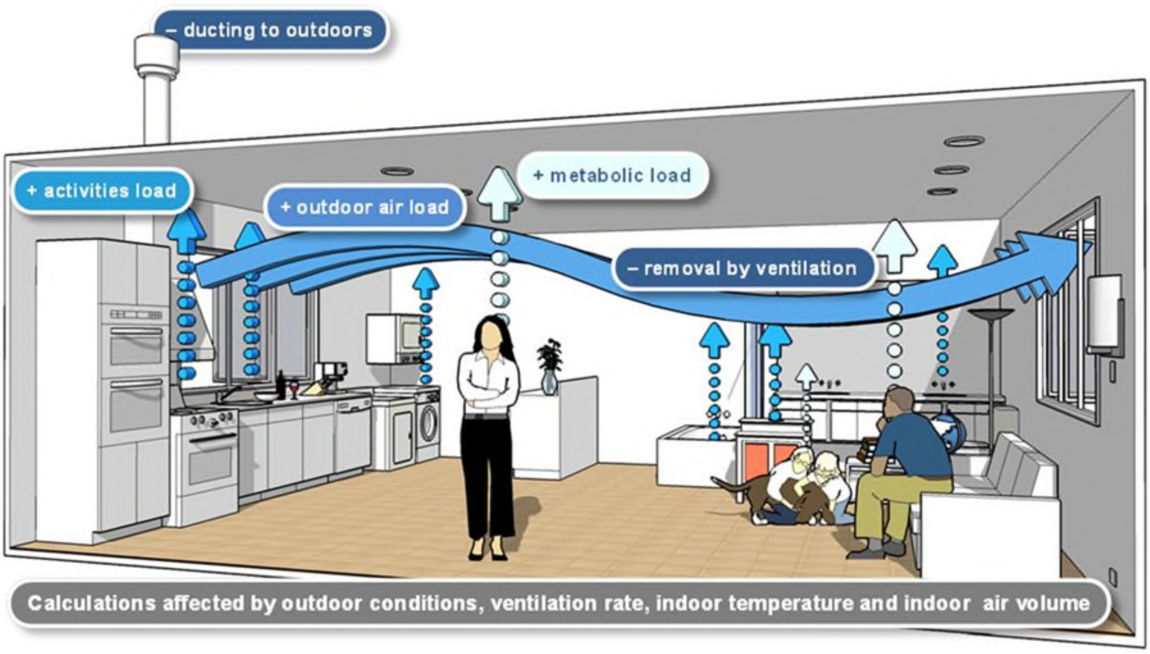
3.3.5 Indoor climate

Differences in temperature and water vapour content between the outdoors and indoors will strongly affect decisions about suitable building envelope design and detailing. Because there is an ongoing exchange of air between outdoors and indoors, the water vapour content of the indoor atmosphere cannot be substantially lower than outdoors unless some form of effective dehumidification is at work. This may be the case for air-conditioned buildings, depending on plant capacity and control arrangements, but is less common in Australian homes and especially during the months when heating is desired.

For design purposes, it is conservative to assume that the water vapour content of the outdoor atmosphere is the starting point for indoor humidity conditions during the heating season.

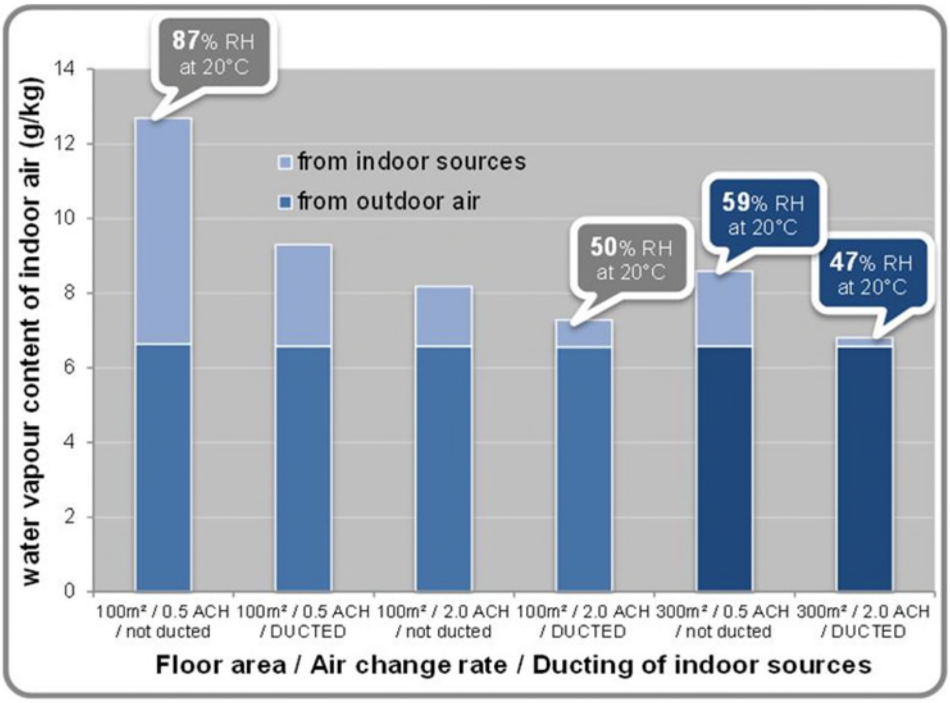
For homes, daily average water vapour levels indoors will depend, at a minimum on what arrives with incoming outdoor air for ventilation, what is added from sources indoors, how much can be diverted directly outside and the rate of removal by ongoing ventilation, as highlighted in Figure 3.31. Approximate daily rates for water vapour release in residential situations appear in Figure 3.33.

Figure 3.31 Factors affecting daily average indoor water vapour levels



Some indoor sources, such as cooking, clothes drying and showering, are quite localised, allowing the water vapour to be captured by exhaust fans which may be ducted directly to the outside. Building occupants, on the other hand, are moving targets and their contributions (the metabolic load) will be removed only by general ventilation. The benefits of ducting indoor water vapour sources to the outside and increasing outdoor air ventilation are demonstrated in Figure 3.32. In recognition of these benefits, the NCC DTS Provisions now require exhaust from a kitchen, kitchen range hood, bathroom, sanitary compartment, or laundry to be discharged to outdoor air, either directly, or via a duct or shaft and additional roof ventilation requirements.

Figure 3.32 Impact of indoor volume, air change rate and ducting of sources on indoor humidity



The first four columns in Figure 3.32 show the effect on indoor vapour content of using ducting and increased ventilation to manage a daily release of 10 kg from indoor sources in a 100 m^2 homes (the 10 kg average value is based on typical rates of release shown in Figure 3.33). The first two columns show a reduction in the water vapour due to ducting all internal sources, whilst the second two columns show further reductions which are gained by increasing the air change rate. The last two columns (in darker blue) indicate the advantage of having a larger indoor volume. The water vapour content of the outdoor moist air (shown in the lower parts of the columns) sets the baseline for indoor water vapour levels and provides the major contribution in all of the examples. Choices about ducting arrangements and outdoor air ventilation rates, however, make considerable differences to the average water vapour content indoors (shown by the overall height of each column).

Whatever is not ducted to the outdoors or carried away by ventilation will be dispersed through the moist air volume in the building. In practice, it is unlikely that perfect mixing will occur, particularly when bathrooms and laundries are often behind closed doors. Indoor sources, concentrated in particular rooms, may raise the indoor water vapour content above the calculated average value. To recognise this possibility, an initial assessment of the impact of indoor water vapour generation can use a smaller building volume than is actually present. Similarly, assuming a low ventilation rate and low levels of outside exhaust will tend to amplify the effect of estimated water vapour released indoors (as demonstrated by the varying examples in Figure 3.32). This approach is adopted in Section 3.3.6, using the psychrometric chart to highlight what may happen if indoor moist air finds its way to parts of the building fabric which are cooled to near-outdoor temperatures.

Figure 3.33 Indoor sources of water vapour in homes and indicative rates of release (Source: BRANZ 2012)

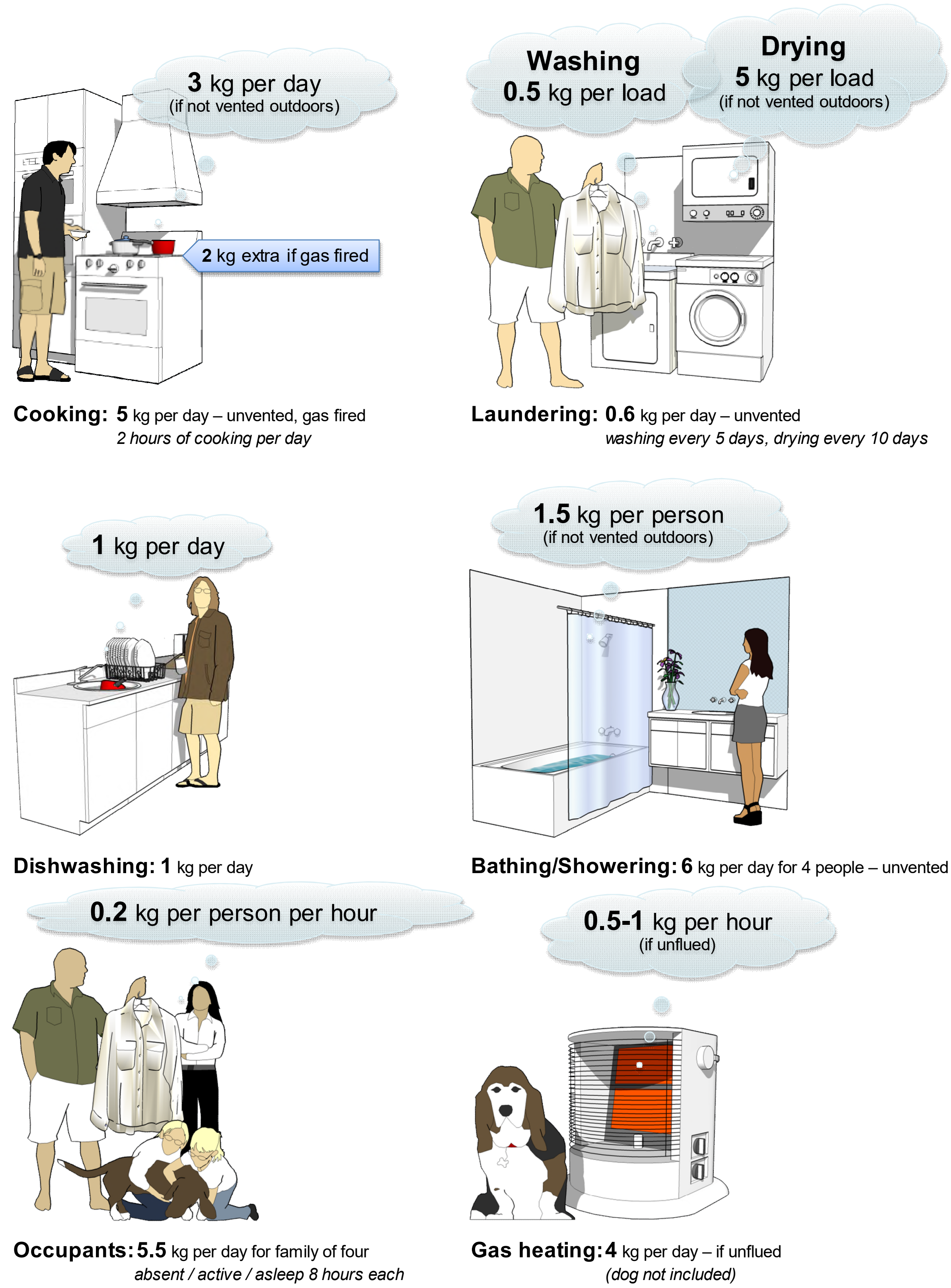


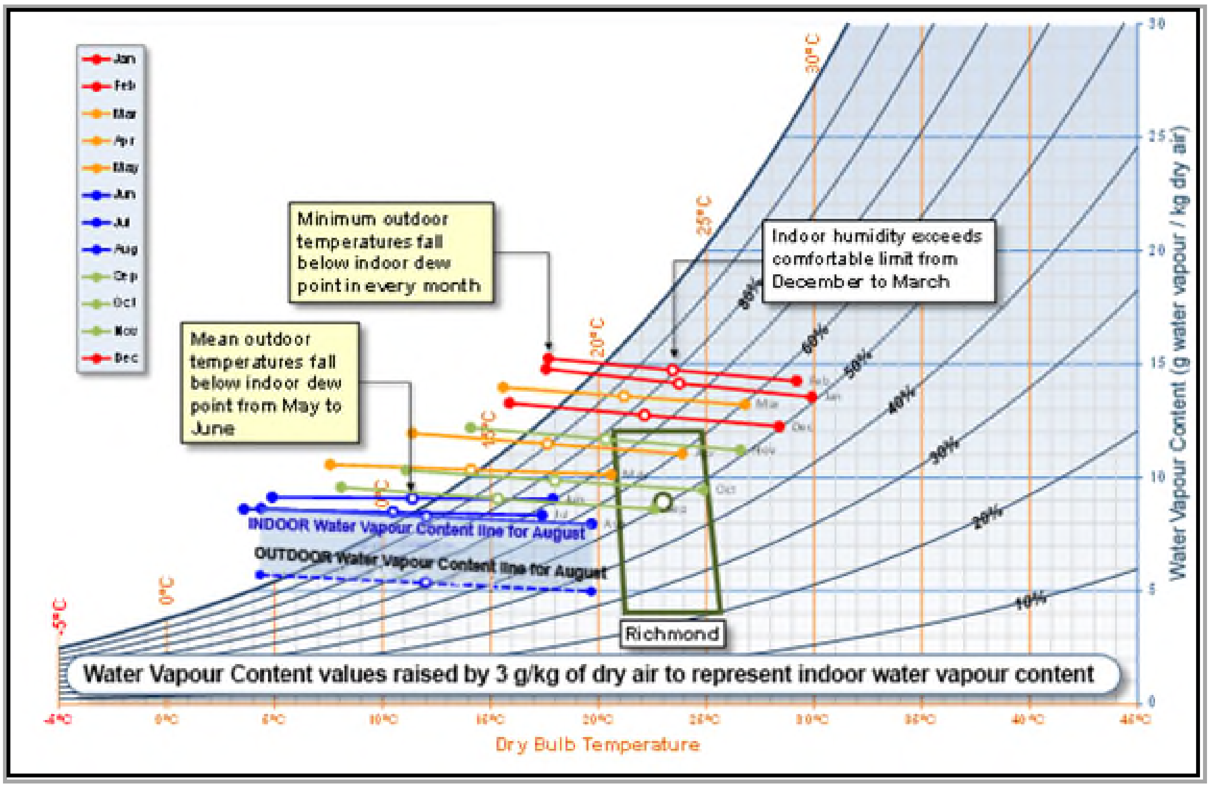
Figure 3.33 suggests that occupants could release a total of about 5.5 kg of water vapour per day if two adults and two children (each releasing half the amount of an adult) were absent for eight hours a day, active for eight and asleep for the remaining eight hours. Domestic activities would contribute another 4.5 kg based on accounting for releases from gas cooking and showering (discharged outside with 70% effectiveness), a ducted clothes dryer (with 90% effectiveness) and fully flued gas heaters. Note that where domestic activities releases moisture and it is not effectively discharged outside, this contribution would be higher.

The daily total of 10 kg for such pattern of occupancy and activity matches the design moisture generation rate recommended in ANSI/ASHRAE Standard 160:2016 for a household of four (occupying three bedrooms). The 10 kg rate in ANSI/ASHRAE Standard 160-2016 was originally set at 14 kg before the release of Addendum B in 2012 with a Foreword stating: "It has become apparent that the residential generation rates in Table 4.3.2 are very high. Changes to Table 4.3.2 are based on recent analysis of measured indoor humidity and ventilation data."

3.3.6 Basic assessment of the impact of indoor water vapour loads

With an estimate of indoor water vapour levels, it is possible to adjust the climate analysis charts discussed in Section 3.3.4 to illustrate what might happen when moist indoor air encounters building surfaces which have been cooled to temperatures close to those outdoors. Figure 3.34 shows the Richmond (NSW) example from Figure 3.30 adjusted for an estimated indoor load of 10 kg in a 100 m^2 (240 m^3) interior ventilated at a low 0.5 air changes per hour (ACH).

Figure 3.34 Water vapour content values adjusted for indoor load – Richmond (NSW)

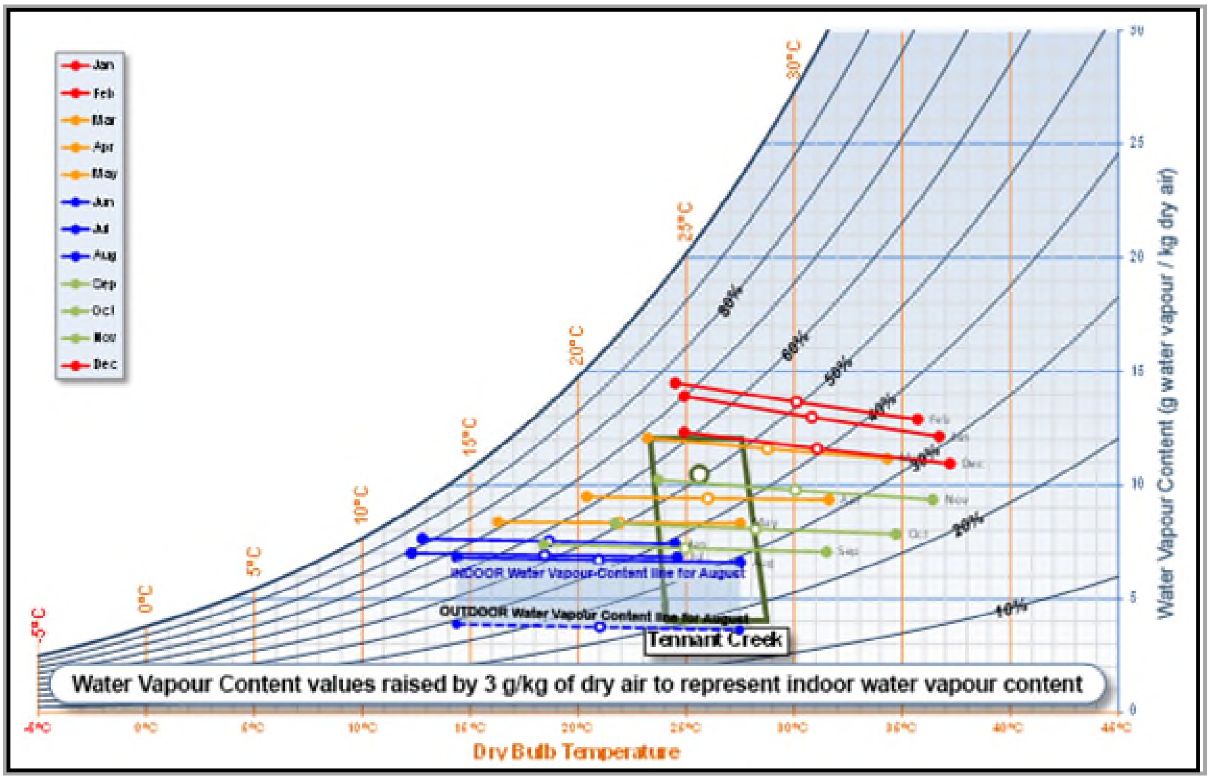


In the adjusted version of the climate analysis chart, all water vapour content values have been increased by a uniform 3 g/kg (on the vertical axis) to represent the approximate impact of the indoor water vapour load. The outdoor temperatures retain their positions on the horizontal axis.

Monthly lines which cross to the left of the saturation curve indicate some potential for condensation. Where only the left-hand end crosses, the condensation may occur overnight but evaporate during warmer daytime conditions (indicated by the right-hand extent of the line. If the mean monthly temperature (at the centre of each line) falls to the left of the saturation curve, the condensation is more likely to persist. Comparing the mean monthly temperatures with lower RH curves provides an indication of conditions that might prevail if most indoor air accumulates in the coldest parts of the building fabric.

To emphasise the strong impact of local climate, Figure 3.35 provides the equivalent comparison for the hot dry climate of Tennant Creek (NT). The same indoor load in this situation produces no indication of temporary or persistent condensation. At monthly mean temperatures, RH in the colder parts of the building fabric remains below 60%.

Figure 3.35 Water vapour content values adjusted for indoor load – Tennant Creek (NT)



The 3 g/kg increase in water vapour content, representing the approximate impact of the indoor water vapour load, is suggested by analysis of 160 climates completed by the ABCB based on a small home size and low ventilation rate. In the alpine climates, the increase should be 3.5 g/kg. These results are conservative for larger and better ventilated buildings and if this seems unnecessarily cautious, the 3 g/kg can be decreased proportionally to volume for larger residential interiors. For a more conservative estimate, a higher indoor load could be used. Within the approximations suggested here, doubling the estimated indoor load from 10 kg to 20 kg would also double the approximate increase in water vapour content from 3 g/kg to 6 g/kg (or 7 g/kg for alpine climates).

The comparisons shown in Figure 3.34 and Figure 3.35 are straightforward to construct and use information readily available for download from BOM. Appendix D.2 shows examples of this approach applied to twelve highly populated Australian climate locations.

For homes, the techniques outlined here could be applied early in the design process, once the location and likely indoor loads have been determined. However, these comparisons are not suggested as a substitute for detailed assessments using recognised risk analysis methods when adverse conditions are indicated.

4 Dry buildings

4.1 Overview

This chapter covers minimising condensation and creating dry buildings including envelopes, conditions inside the building envelope, RH and condensation in interstitial spaces, control layers for water, air, vapour and thermal control and risk assessment calculation methods and software. At the end of this chapter are design, construction and occupant checklists that provide practical suggestions to minimise condensation risk.

4.2 Envelopes (claddings, linings and control layers)

Every building project, however modest, seeks to exert some control over local conditions. The aim may be just a patch of shade and shelter from the rain or more elaborate protection from uncomfortable extremes of the outdoor climate (Figure 4.1).

Figure 4.1 Climate control by the building enclosure

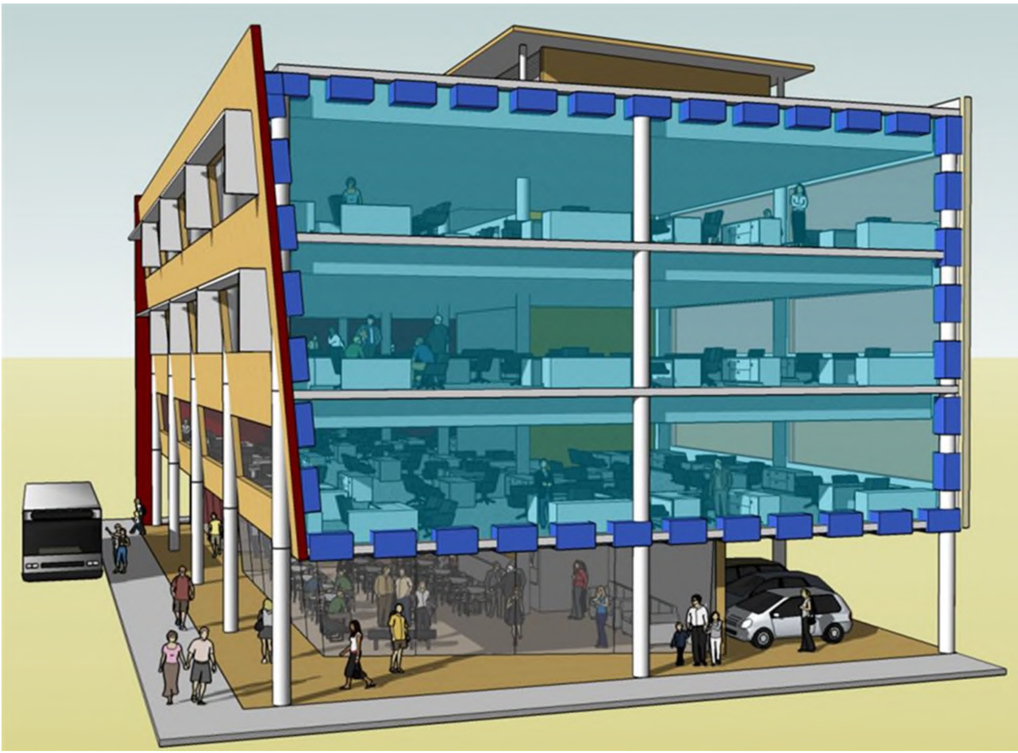
Once a building is enclosed and occupied, the indoor and outdoor climates unavoidably diverge. When the weather is coldest or hottest, any heating or cooling will amplify the differences. The office building in Figure 4.2 provides a typical example. In a warm, humid climate, occupants may hope to be out of the rain and sun, less distracted by outside noises, able to work in cooler temperatures with controlled air movement and lower humidity and to have some choice about daylight levels and the spill of sunlight across workspaces.

In meeting just some of these expectations, the indoor climate becomes relatively stable with predictable temperatures, air pressure and RH. Outside, an active weather system remains at work, and these two environments are seeking to redress imbalances on each side. This can be mitigated through careful design and construction of the building envelope.

Alert

"Envelope" is a defined term in the NCC used in the energy efficiency provisions. Refer to Schedule 1 of the NCC for more information.

Figure 4.2 Building envelope to sustain preferred indoor climate

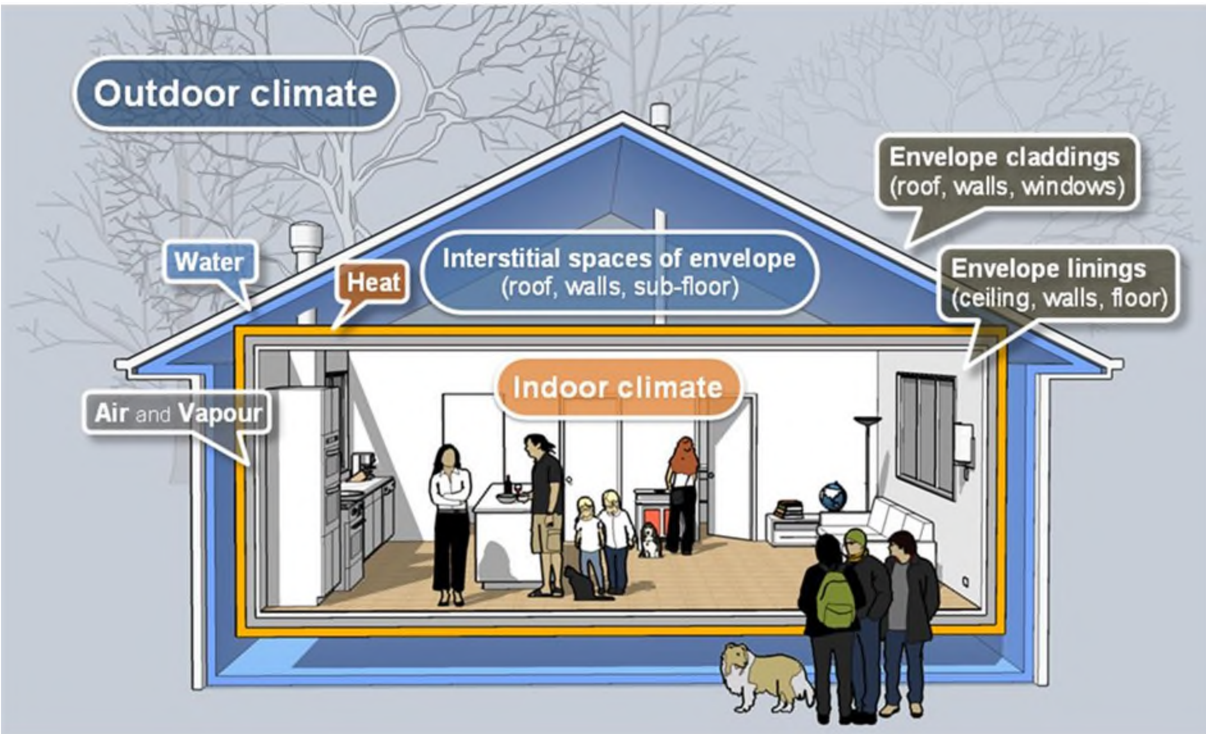


In Figure 4.2, a blue dotted line highlights the boundaries of an envelope which protects air-conditioned office interiors from warm, humid conditions outside. The differences in temperature, air pressure and water vapour dew points across the building envelope drive the flows of heat, air and moisture which the envelope must control. To avoid problems with excessive RH and condensation at least four layers of control are needed:

- **Water**: To deal with water vapour, the envelope must first have liquid water under control. Rain and groundwater are the main contributors to the surface wetting of buildings, often leading to deeper migration into the envelope and a handicap in avoiding condensation.
- **Air**: Since water vapour rides with air (as can heat), the envelope should be able to keep air moving along intentional pathways, as far as possible. Leakage through gaps, cracks and holes will subvert strategies to control the diffusion of water vapour.
- **Water vapour**: Denied a free ride, water vapour can find its way through permeable building materials by diffusion. Controlling the diffusion of water vapour will not necessarily mean blocking it entirely. It may be enough to restrict (or retard) diffusion in one season to benefit from drying in another. Subject to climate and building fabric design, in some buildings you may wish to block the flow of the vapour, whilst in others you may wish vapour to breathe into and out of the built fabric.
- **Heat**: Controlling the flow of heat is essential to keeping envelope surfaces above dew point and to sustaining an indoor climate with acceptable RH levels. Additionally, in hot and humid climates, the creation of cooled surfaces from air conditioning can also promote condensation.

In a perfect world, these control functions would be available in a single material (and a choice of colours) to form the entire envelope. Instead, extreme weather, physical security, economics and the practicalities of construction mean that multiple materials are usually needed to form effective control layers in the interstitial spaces between the envelope's exterior claddings and its interior linings (Figure 4.3).

Figure 4.3 Control functions in the interstitial spaces of the building envelope



The control layers need to be continuous on all sides but the function can pass from material to material in the building fabric provided each can do the job and appropriate overlap or joining occurs at every transition.

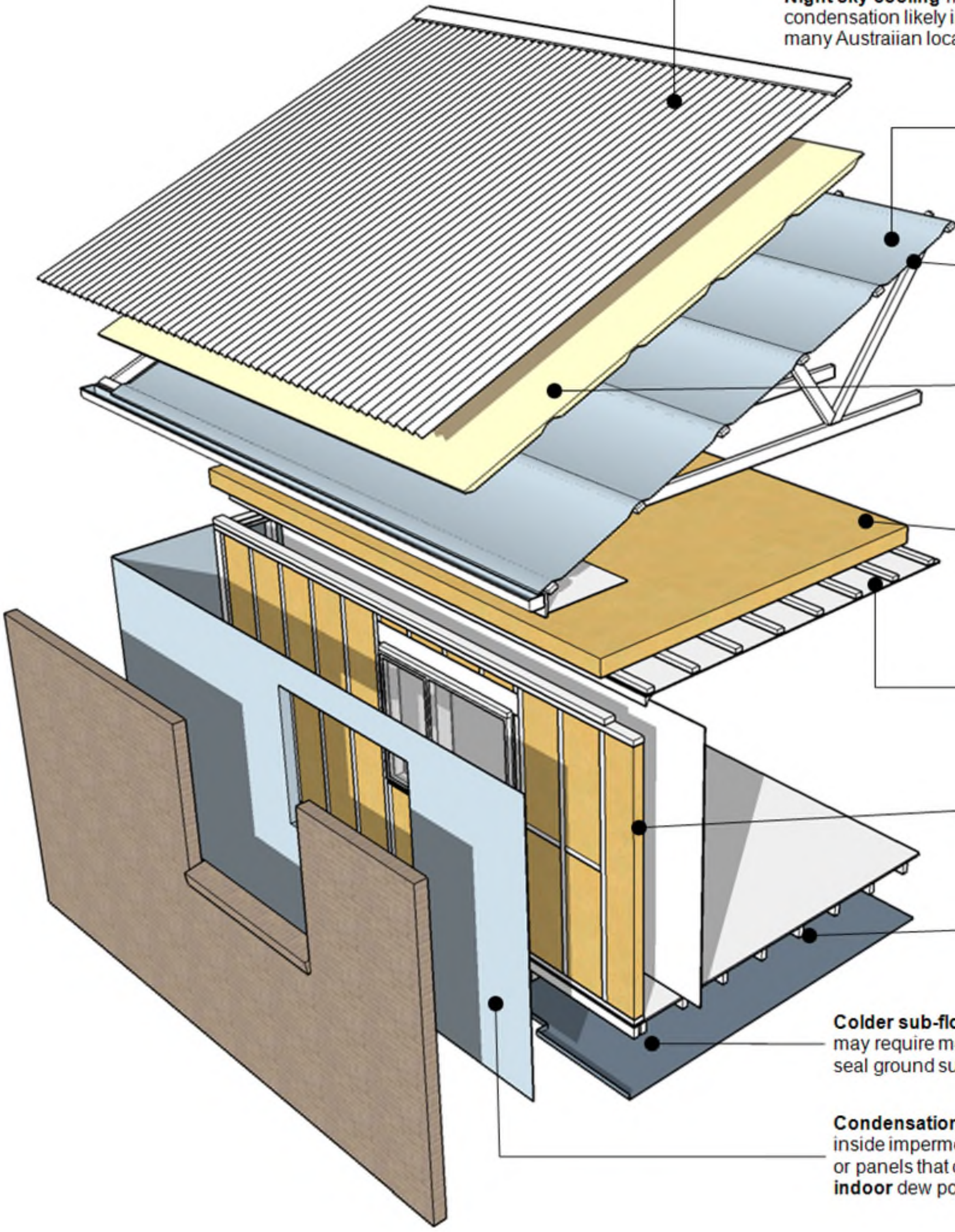
It is especially important when dealing with unfamiliar conditions brought about by new materials and techniques, changing patterns of building use and shifts in building regulation.

4.3 Changing conditions inside the building envelope

Possible impacts of the NCC energy efficiency measures on condensation risk are acknowledged in the provisions but these regulatory changes are one part of broader trends that have converged in recent decades to increase risk factors explained in this handbook.

The cumulative impact of these trends is that the interstitial spaces of the envelope will tend to have higher RH than traditionally expected and cooler surface temperatures which are nearer to the dew point of indoor air unless proportionate efforts are made to reduce the amount of water vapour going into them and to help it leave. Figure 4.4 shows possible impacts on parts of an envelope typical of residential masonry veneer construction, in the context of heating season condensation risk. These risks are manageable once they are understood.

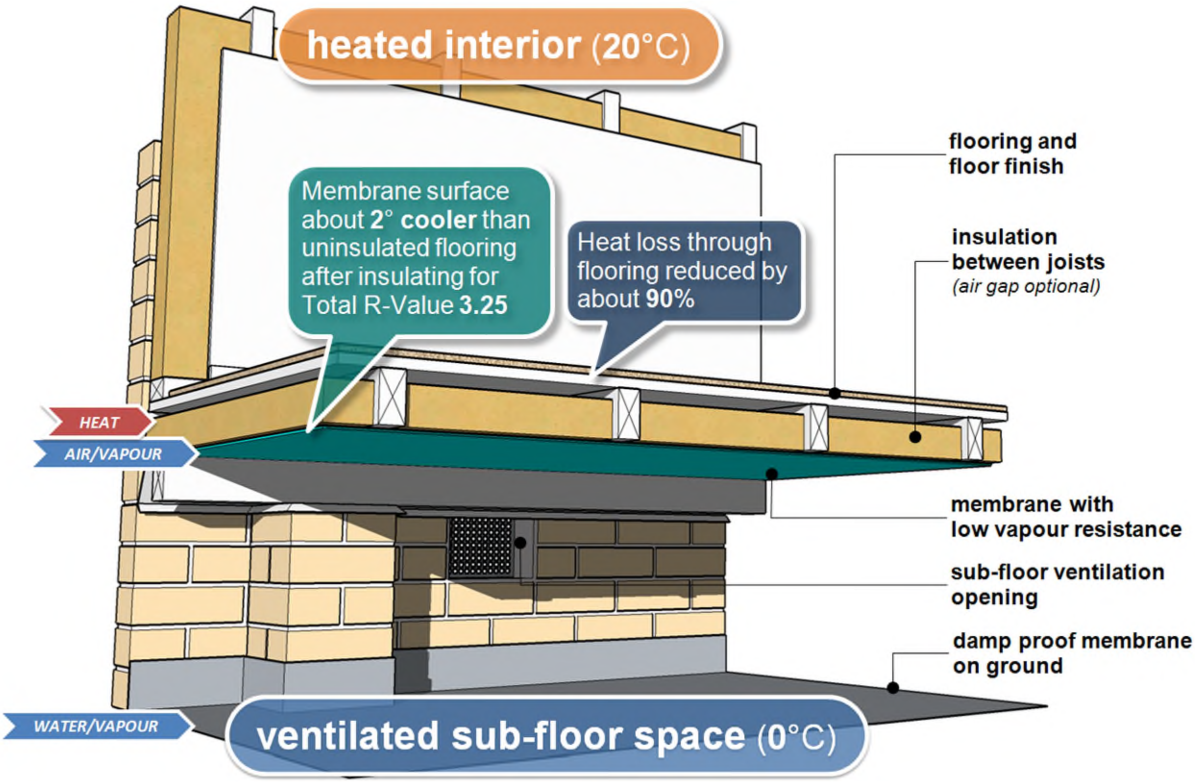
Figure 4.4 Changes to interstitial envelope conditions for a typical masonry veneer house



4.4 Higher relative humidity in interstitial spaces

Lower temperatures in interstitial spaces around an insulated interior are one of the expected effects noted in Figure 4.4. In cooler spaces, RH will be higher and framing timbers can take up more water vapour, possibly increasing their risk of mould growth and timber decay. Some measure of the effect on interstitial temperatures and humidity can be seen in Figure 4.5 which illustrates an insulated timber floor intended for an alpine/cold climate.

Figure 4.5 Suspended timber framed floor - insulated between joists (alpine/cold climate)



The suspended timber framed floor over a ventilated sub-floor space has insulation installed between the joists and supported on a membrane with low water vapour resistance. This arrangement follows an example in the British Standard BS 5250:2011+A1:2016 "Code of practice for control of condensation in buildings" (Figure F.6). It relies on ventilation to keep the dew point in that space low and close to the outdoor level.

4.5 Condensation in interstitial spaces

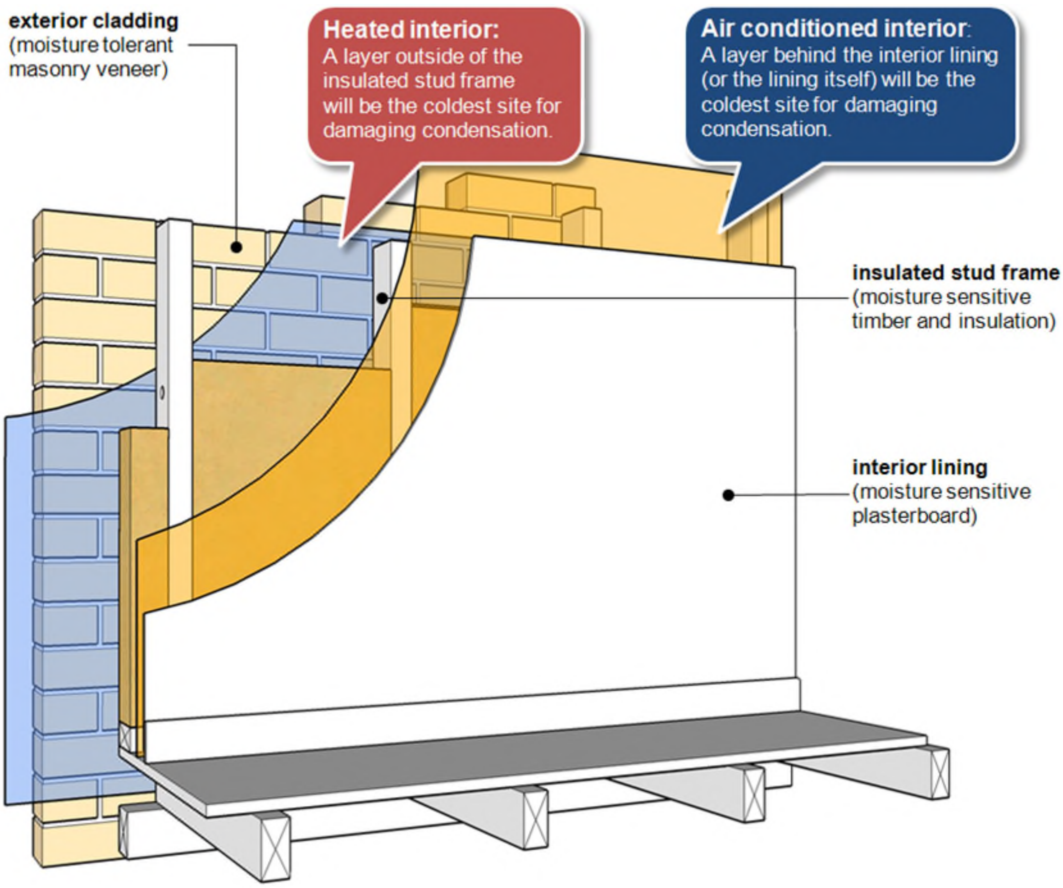
Figure 4.4 identifies some of the sites within the envelope where condensation may form during the heating season. Confirming potential for condensation may be a useful first step but the key considerations are:

- the amount of condensate formed
- how long it might remain in liquid form before drying conditions return
- how likely it is to wick, flow or drip from the condensing surface and
- which other parts of the building fabric might be affected by it.

Assessing these questions in any detail calls for analytical techniques of the sort outlined in Section 4.9.

Given the location of the insulation layer (internal, cavity or external), identifying the critical interstitial surfaces in a roof, wall or floor can begin with the question: “Which is the coldest surface in this wall, floor, or roof where condensation will matter?” Figure 4.6 considers critical condensation surfaces in a masonry veneer wall.

Figure 4.6 Critical condensation surfaces in masonry veneer envelope walls



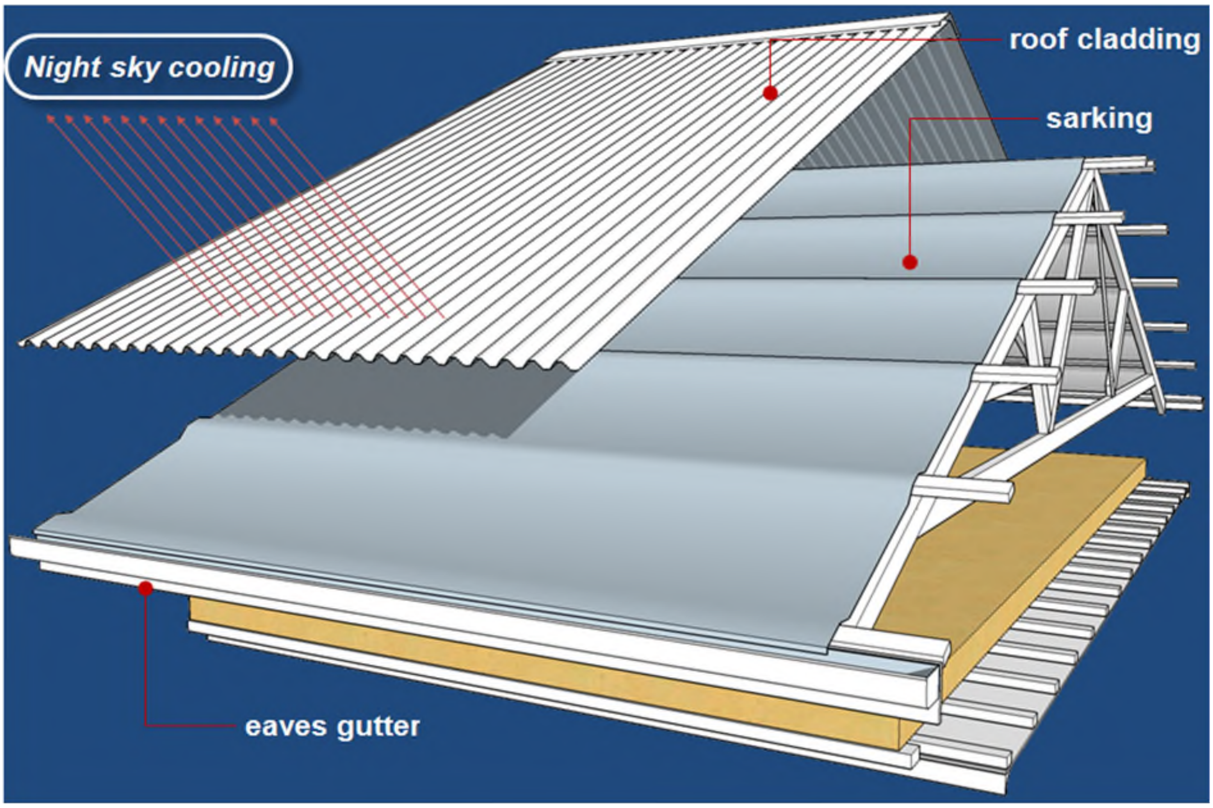
In Figure 6.6, the timber framing will be at risk of mould and decay if accumulating condensate drives up its moisture content and the insulation will lose much of its thermal resistance if it becomes waterlogged. Water in the stud frame space will easily find its way into the occupied interior of the building, damaging wall linings, trims and finishes.

4.6 Water control layers and drainage planes in an envelope

4.6.1 Roof cladding condensate

Although condensation under a metal deck roof is probable, its impact can be managed by the installation of sarking, which can collect condensate dripping from the non-absorbent underside of roof sheeting and drain it to the guttering (Figure 4.7).

Figure 4.7 Draining condensate formed on the underside of roof cladding



The condensation is caused by outdoor air circulating through roofing corrugations and may cool to several degrees below the outdoor air temperature. The risks depend almost entirely on the outdoor climate since only outdoor air is circulating above the sarking.

Comparing the outdoor average dew point with the mean minimum temperature in each month will quickly highlight the likelihood of this source of condensation (See Section

3.3.3 and the map in Appendix D.1). A review of climate data for 160 Australian locations shows that roof cladding condensation can occur in 95 of locations without any consideration of night sky cooling. Reducing the mean minimum temperature by just two degrees, as an allowance for its effect, shows that 140 locations could be affected, highlighting that all roofs have risk to experience some condensation. The climate data also provides information to assess the daytime drying potential and value of roof space ventilation to reduce the prospect of persistent damaging moisture.

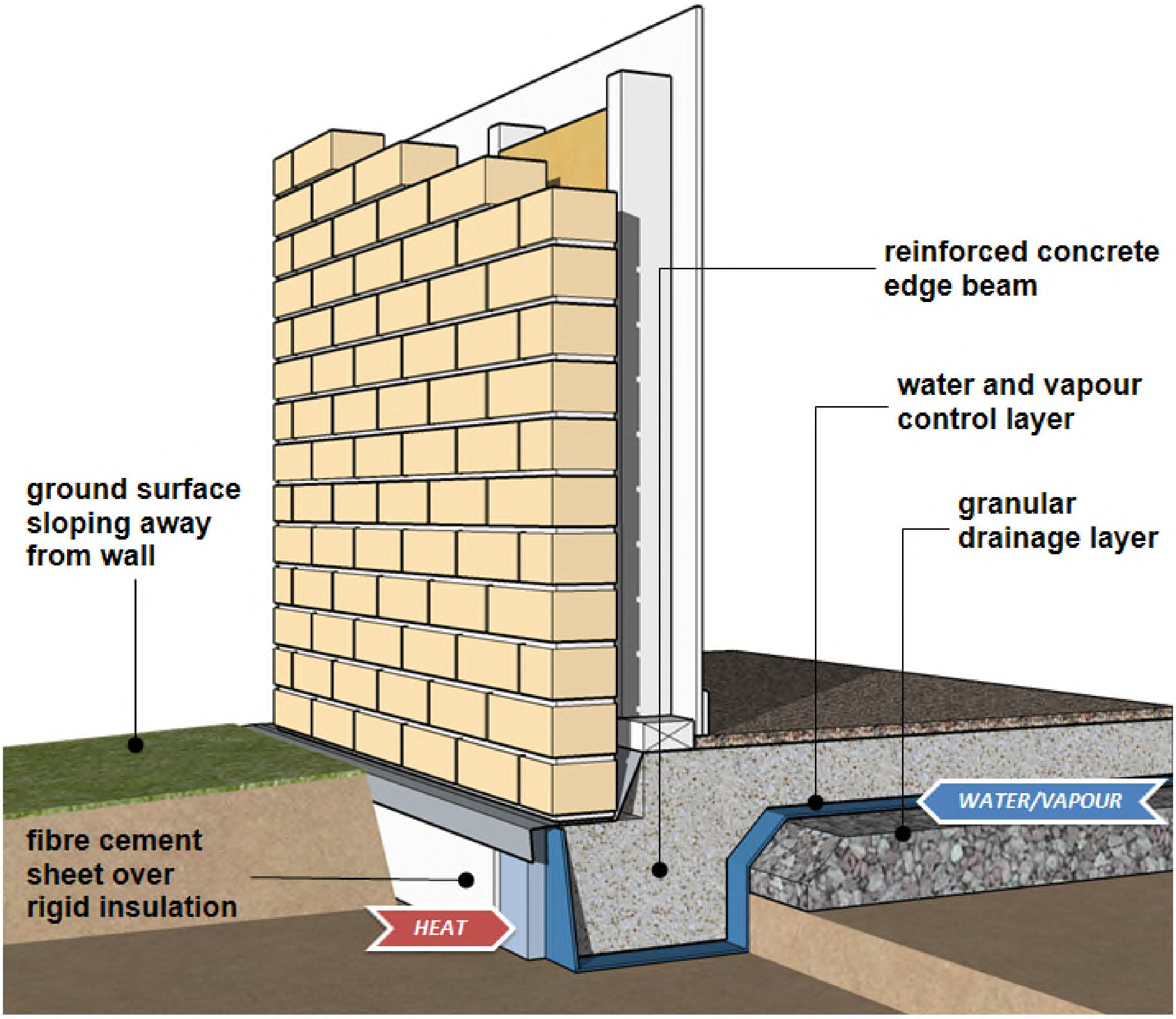
The sarking membrane in this roof serves as a water control layer (or drainage plane) to dispose of condensate which could otherwise drip onto any ceiling or insulation below. It must be waterproof but need not necessarily offer a high resistance to water vapour. Some capacity to absorb and temporarily detain water could also be an advantage when condensate levels are likely to be high or where there is no clear path for drainage to the gutter, such as under low pitched roofs, where the profile of the roof sheet is limited or the fixing methods form a barrier to drainage.

Clay and concrete tiles have at least some thermal mass and moisture storage capacity, as well as absorbent under surfaces, making it less likely that dripping condensation will form under them. A waterproof sarking may still be needed in these cases to catch and drain any leakage through tile joints. A highly vapour permeable sarking could provide the necessary waterproofing while also making use of the air-open tile surface to lower the dew point in the ventilated roof space.

4.6.2 Groundwater

With groundwater being one of the principal sources of burden on the envelope’s moisture storage and drying capacity, attention to the water control layer where the envelope meets the ground is also essential (Figure 4.8).

Figure 4.8 Slab on ground floor water control arrangements



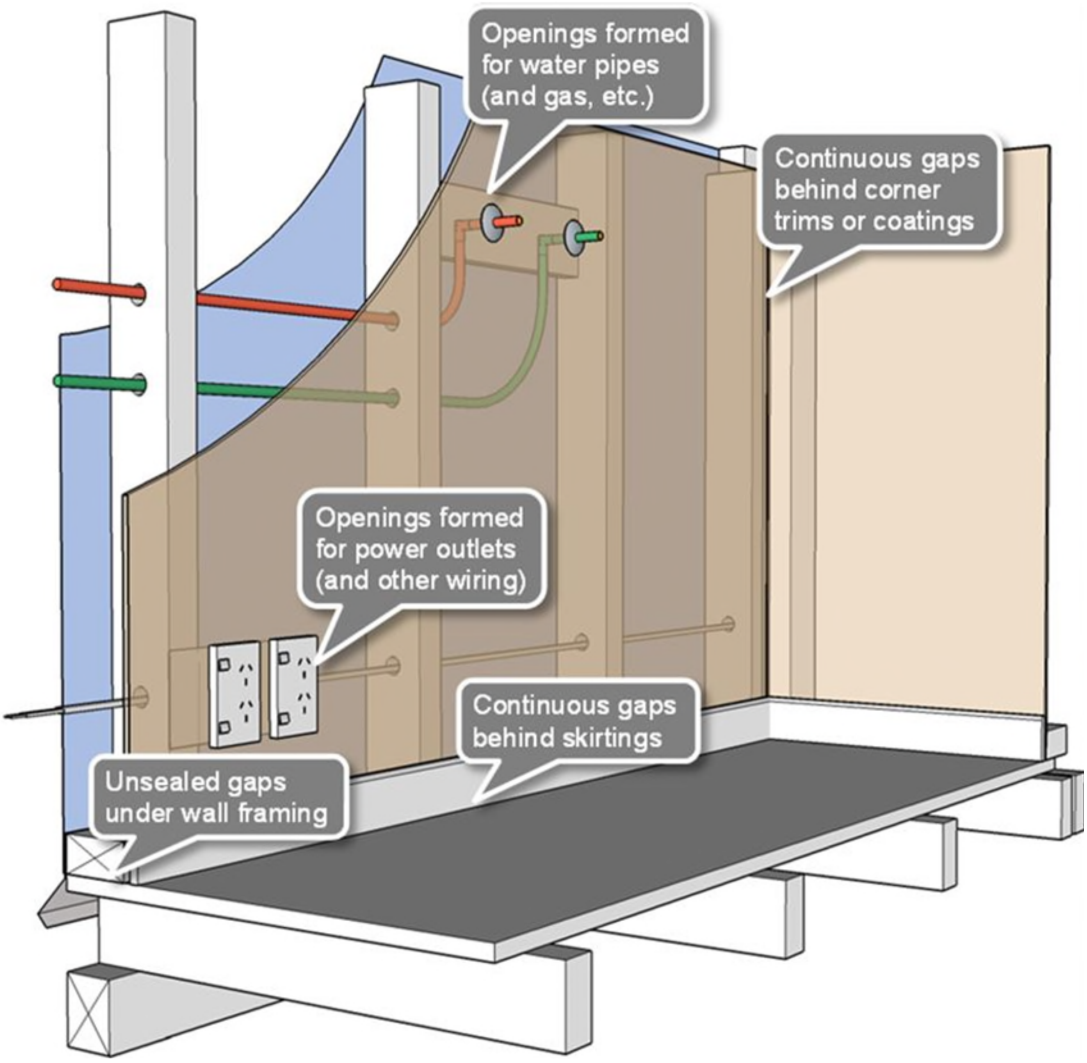
To minimise water and vapour pressure under the slab and to create a capillary break, a 100 mm granular drainage bed should be formed using coarse aggregate. The bed should discharge collected water clear of the building base and be vented to the atmosphere to assist drying.

A single pliable membrane, with high resistance to both water and water vapour transmission, can merge the water and water vapour control functions below the slab. The membrane should be turned up the exterior face of the slab inside rigid insulation which is protected by water tolerant facing such as fibre cement sheet, primed on both faces and all edges. The insulation and its protection should be in the formwork when the slab is poured, be unaffected by moisture, as well as rigid enough to deal with impacts and the pressure of back filling.

4.7 Air control layers

Many interior lining materials could serve to control both air and water vapour movement but their integrity is frequently compromised by panel joints and corners and penetrations for pipes, drains, wiring, cables, flues and ducting (Figure 4.9). The cumulative effect of such leaks is easily overlooked.

Figure 4.9 Some typical air and water vapour leakage sites through internal wall linings



At ceiling level, other shortcuts for air and water vapour movement are often available (Figure 4.10). Unsealed downlights, in particular, can short circuit. Such leaks can be reduced considerably by installing surface mounted fittings or downlights designed to dissipate heat safely through an unventilated shroud or housing. For electrical and fire safety, enclosed shrouds should not be retrofitted to unsealed light fittings except on the specific advice of the fitting's manufacturer that it is safe to do so.

Figure 4.10 Some air and water vapour leakage sites through ceilings[5]

Alert

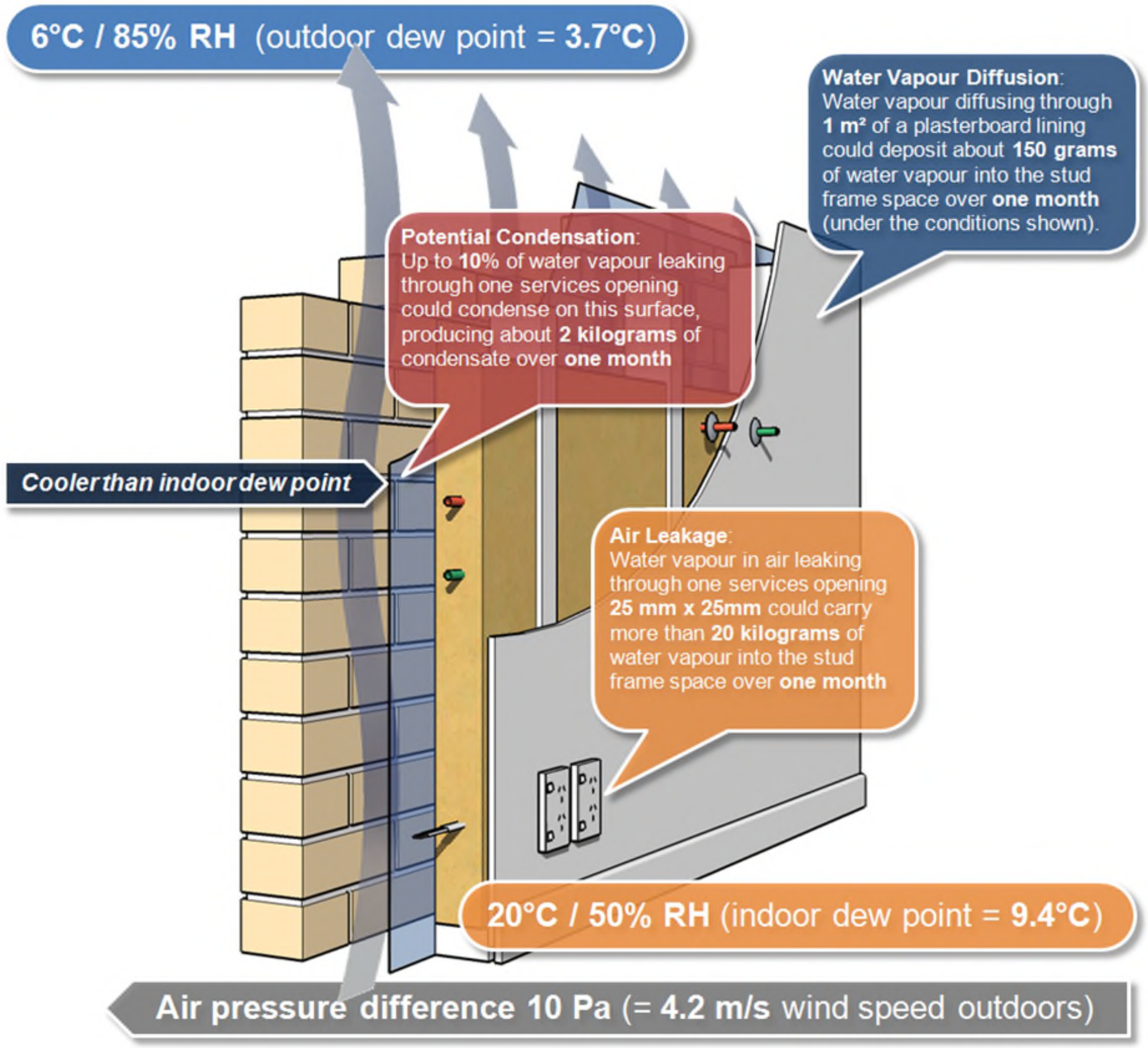
The NCC energy efficiency provisions in J5D6 of NCC Volume One and 13.4.5 of the Housing Provisions require an exhaust fan to be fitted with a sealing device when the fan serves a conditioned space or a habitable room in climates zones 4, 5, 6, 7 or 8. As an example Explanatory information for 13.4.5 states an exhaust fan is considered to be adequately sealed if it is fitted with a filter such as the type commonly used in kitchen range hoods. These are minimal measures, which help to reduce energy wastage. When dealing with water vapour leakage in condensation prone climates, greater attention may be needed with sealing and ventilation strategies.

For downlights and other openings through ceilings, the extra insulation requirements of 13.2.3(5) address only thermal effects and are not expected to mitigate condensation risks from leakage of water vapour into the roof space.

Figure 4.11 compares rates of water vapour transport by diffusion through each square metre of a plasterboard wall lining and by air leakage through a single small opening in the lining for a pipe or cable.

[5] Note the NCC 2022 DTS Provisions for condensation management no longer permit exhaust from a laundry to be discharged into a roof space. Refer 10.8.2(2) and (3) of the Housing Provisions.

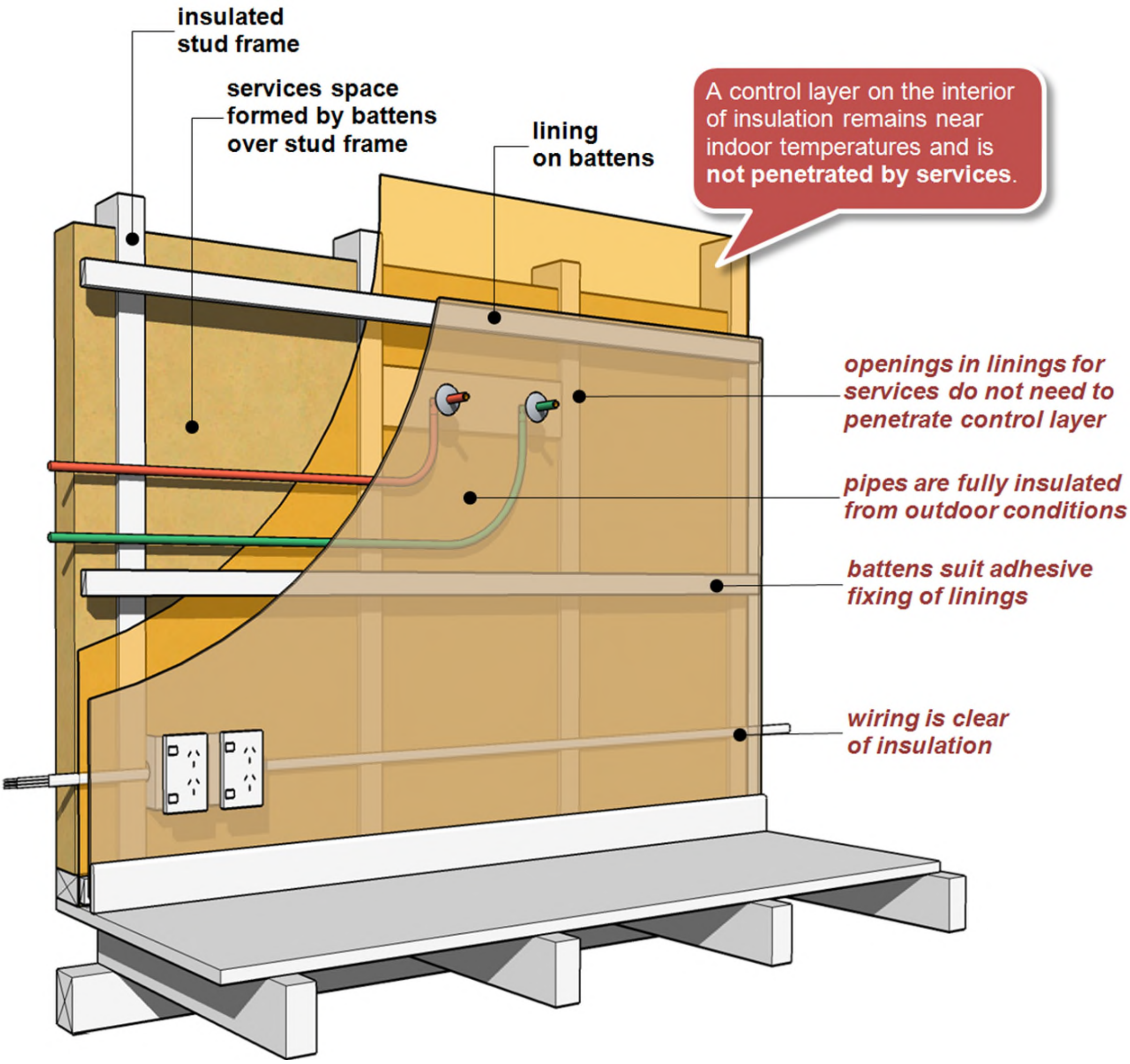
Figure 4.11 Comparison of water vapour transport by diffusion and by air leakage



Not all of the water vapour carried by air leakage will remain in the stud frame space. Much of the flow may find relatively direct pathways to the outside. The heat in the air and water vapour may warm these paths enough to keep them above the dew point of the airborne water vapour. Where the leakage must follow extended or convoluted paths, however, the water vapour can cool to its dew point and condense. These sorts of leaks have been estimated to account for 5-10% of the total volume of moist air flow through the building envelope (Zirkelbach 2009).

Given this, it might seem a significant limitation for current condensation risk assessment methods and software to focus on diffusion rather than air leakage as apart from a drainage cavity; diffusion remains the key vehicle for interstitial moisture and the likely source of condensation.

Figure 4.12 Battened services space to avoid penetration of control layers in envelope walls



Emphasising the importance of effective air control, the British Standard BS 5250:2011+A1:2016, Annex G, advises that a dedicated space for the installation of services should be formed behind interior surface finishes or linings. This will allow an air control layer to be formed on the interior side of wall insulation without penetrations for services, as illustrated in Figure 4.12.

4.8 Water vapour control layers

Once it is clear that the dew point temperature of either the indoor or outdoor atmosphere is substantially higher than likely interstitial surface temperatures, there will be an understandable impulse to put a barrier between the water vapour and those colder surfaces to fix possible condensation problems once and for all. A disappointing complication of that approach is that North American and European experience in recent decades has shown that the barrier might solve the problem for one season but not for all.

In very cold climates, vapour barriers installed on the warm side of the envelope aim to limit the migration of warm indoor water vapour through building fabric which becomes progressively colder in its outer layers. In tropical climates, the same logic allows a vapour barrier on the warm, outdoor side of the envelope to restrain water vapour driving towards surfaces cooled by an air-conditioned interior. This approach can work in persistently cold climates. It can work in constantly warm and humid tropical climates. When used in climates with mixed seasons, it has been found to create more difficulties than it solves.

Only the alpine climates in Australia are likely to meet this test. Although some locations in Australia have just one dominating season, most have mixed climates. The growing use of air conditioning allows the creation of summertime indoor climates which will reverse the direction of vapour flow and confound assessments of where to put the vapour barrier.

John Straube (2001) confirms Lstiburek's observations:

> *"In many practical situations, a low-permeance vapour barrier will not improve hygrothermal performance and may in fact increase the likelihood of damaging condensation or trapping moisture in the system. A common misconception regarding low-permeance vapour barriers is that their inclusion where one is not technically needed provides an extra level of performance and resistance to moisture problems. Quite the opposite is true."*

Joseph Lstiburek's commentary on managing moisture in buildings sets out principles for managing water vapour flow through building assemblies using materials that will best balance competing needs to prevent wetting of the building fabric but to encourage drying. The principles are paraphrased below (Lstiburek 2011b):

- Avoid using a vapour barrier where a retarder will suffice and avoid retarders where vapour permeable materials will suffice.
- Avoid installing vapour barriers on both sides of assemblies to allow drying in at least one direction through the assembly.
- Avoid installing vapour barriers on the interior side of assemblies which enclose spaces cooled by air conditioning.
- Avoid impermeable interior finishes (e.g. vinyl wall coverings) to the envelope of air-conditioned buildings.
- Ventilate building interiors to achieve an acceptable specific ACH (Lstiburek refers to ASHRAE Standards 62.2 or 62.1 for low rise residential or commercial buildings).

Alert

In the DTS Provisions of NCC Volume Two, H4D7(1) states AS 1668.2 (Mechanical ventilation for acceptable indoor air quality) satisfies H4P5 for a mechanical ventilation system, except for an exhaust fan from a sanitary compartment, laundry, kitchen or bathroom. In addition, H4D7(2) identifies Part 10.6 of the Housing Provisions as describing the requirements for natural ventilation in terms of opening sizes.

NCC Volume One has similar provisions in F6D7 for natural ventilation but F6D6 requires a mechanical ventilation or air conditioning system to comply with AS 1668.2 and AS/NZS 3666.1.

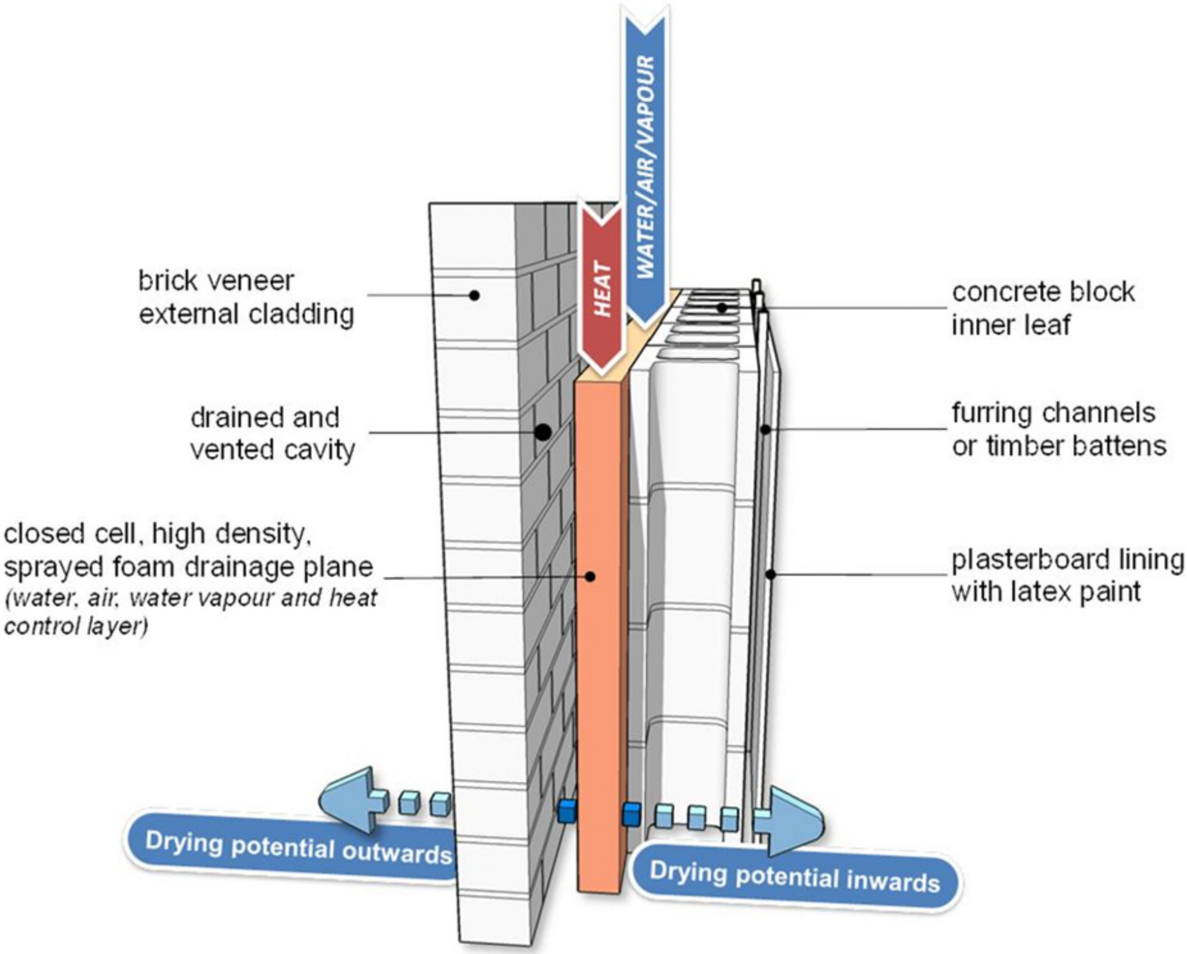
Lstiburek distinguishes vapour barriers, intended to provide the highest resistance to the passage of water vapour through a building assembly, from vapour retarders which have defined lower levels of resistance. Materials which cannot provide even the lowest resistance expected of a vapour retarder are termed permeable.

Two cases are illustrated in Figure 4.13 and Figure 4.14 to show implementation of Lstiburek's design principles. Their success in many North American regions might offer some confidence that well considered approaches can provide robust service across a range of climate conditions.

4.8.1 Water vapour control in walls

The wall in Figure 4.13 shares the brick veneer and concrete block construction of a wall that Lstiburek (elsewhere) dubs the "institutional wall" and considers to be "the best wall we know how to construct". The "clever wall" differs from the "institutional wall" only by using a single material to achieve all four principal control functions. A closed cell, high density foam (32 kg/m^3), spray applied to the concrete block leaf, serves to control the movement of water, air, water vapour and heat across the assembly.

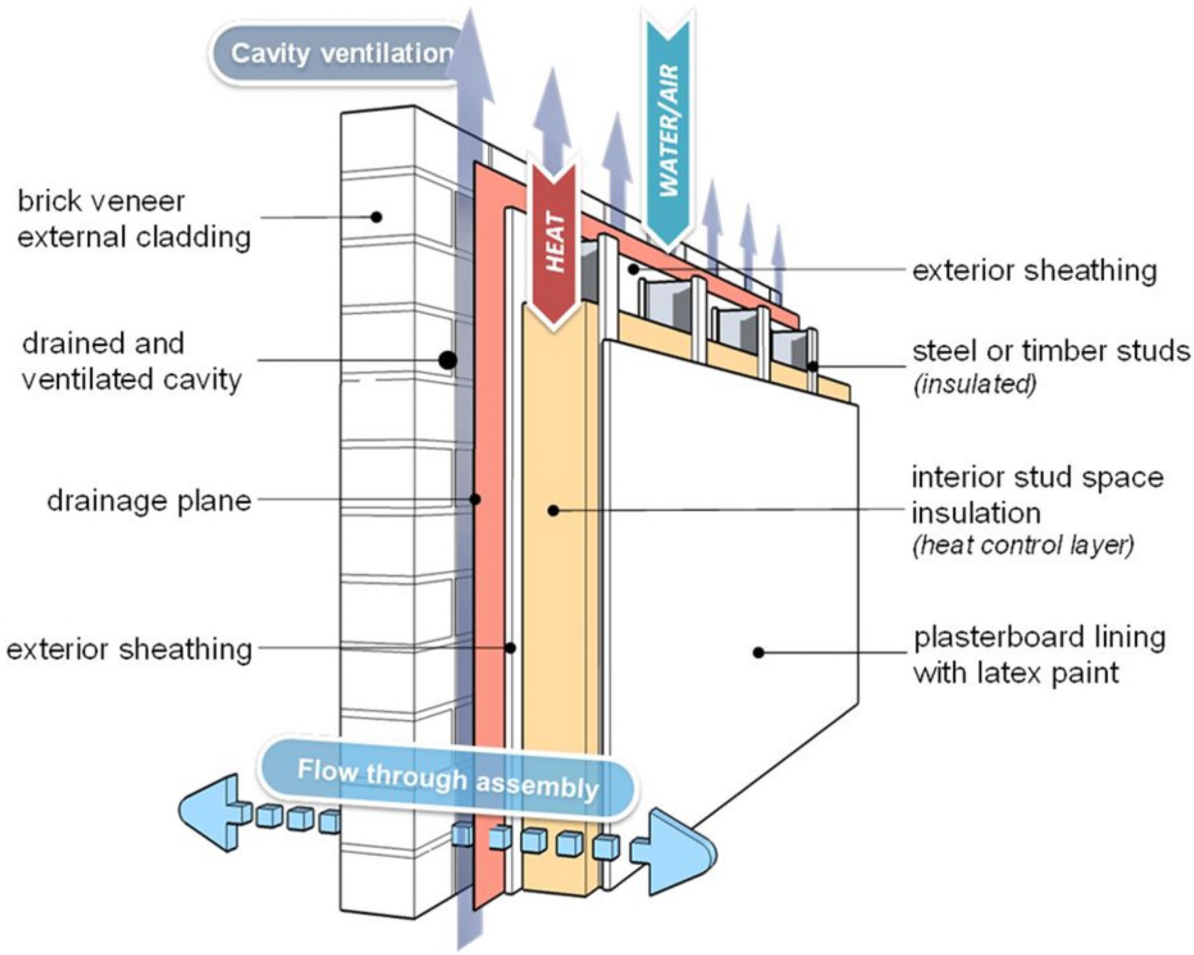
Figure 4.13 Joseph Lstiburek's 'Clever Wall' - using a single material for four control functions (Source: Lstiburek 2010, Figure 7) (Note: Latex paint is a water-based paint)



The exterior surface of the foam forms a drainage plane to discharge any penetrating water from the cavity and this cavity must be drained and vented ("vented", in this context, means only that the cavity can respond to changes in atmospheric pressure. It does not necessarily need to encourage the through flow of air). Since the high-density spray foam has a high resistance to water vapour, the components on each side of that layer are expected to dry away from it in one direction only. Whilst spray foam is not commonly used in Australia, the right combination of bulk insulation and membranes could be substituted.

By contrast, the residential wall in Figure 4.14 relies on being able to dry in both directions.

Figure 4.14 Insulated stud frame wall with brick veneer cladding
(Source: Lstiburek 2011b, Figure 6) (Note: Latex paint is a water-based paint)



The wall assembly in Figure 4.14 shares many of its elements with Australian brick veneer domestic construction. To achieve drying in both directions, materials with low resistance to water vapour are needed at all layers across the assembly, including the drainage plane. The drainage plane must be waterproof but also have a high vapour permeance. If the material chosen offers a high vapour resistance, then the drying strategy of the assembly will fail. Suitable products are available in Australia but there is considerable confusion in the market, which is discussed later in this section.

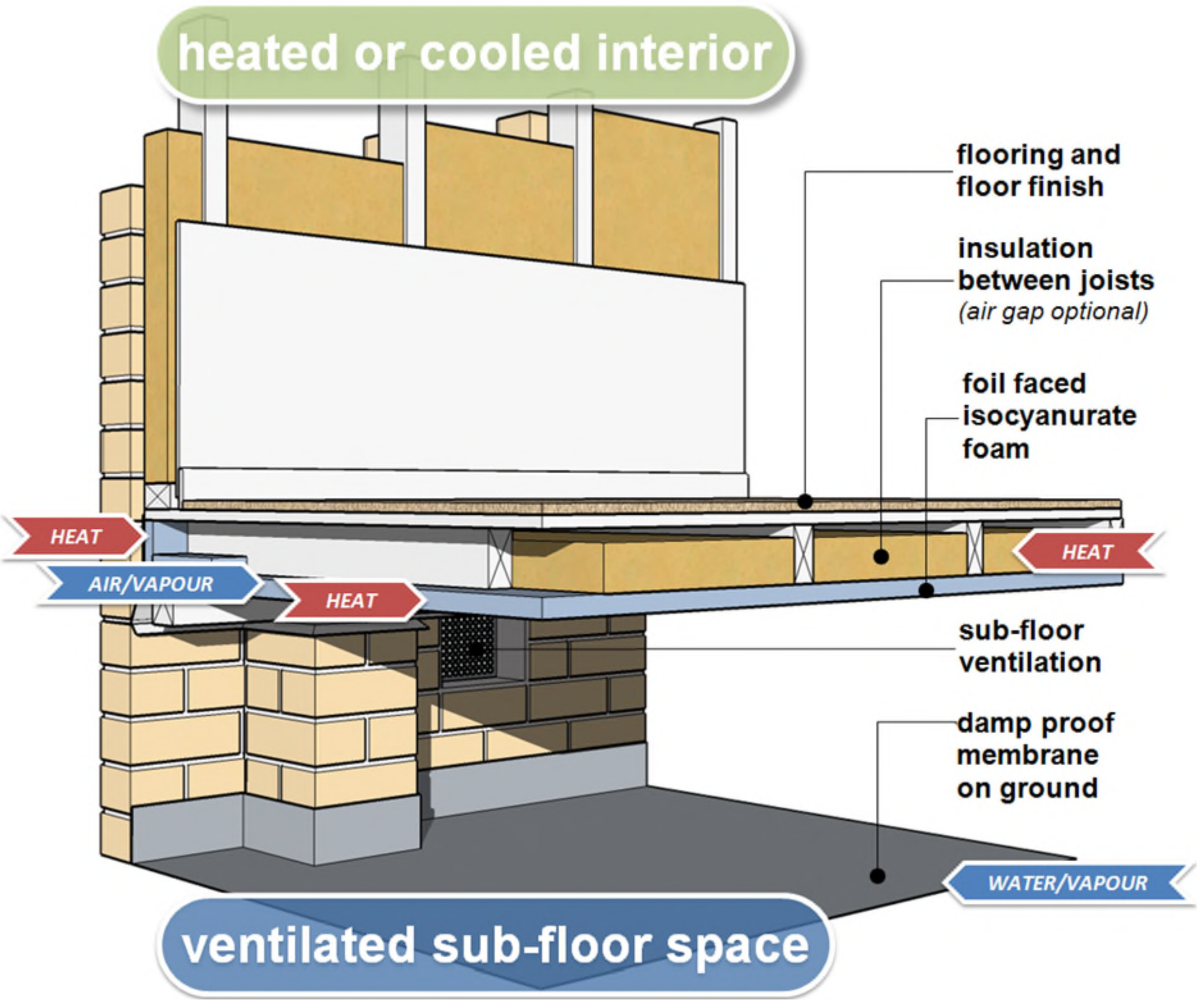
The wall differs from Australian practice by having full sheathing applied to the exterior face of the stud frame. The absence of such sheathing here would reduce the moisture storage capacity of the assembly and require caution about adopting it in condensation prone climates and cooler climates.

4.8.2 Water vapour control under floors

The suspended timber floor shown in Figure 4.5 offers intentionally low resistance to the diffusion of water vapour into the ventilated sub-floor space to allow higher indoor water vapour levels to be dissipated in the ventilating air stream. Where this practice has been applied to air-conditioned houses in the US, problems have emerged with inward vapour drive from the sub-floor space under summer conditions (Lstiburek 2008). The migrating water vapour can condense on surfaces with high vapour resistance such as vinyl flooring or the bases of furniture and cupboards in direct contact with the floor. In the high RH created within the fibrous insulation, timber framing is at risk of mould and decay.

Attempting to minimise inward diffusion by installing foil faced foam insulating board as a vapour control layer under the joists (Figure 4.15) requires an air and vapour tight installation to be achieved under difficult working conditions. If successfully sealed, the foam insulating layer could be at risk of trapping any liquid leaking through the floor.

Figure 4.15 Suspended timber framed floor with summertime risk of inward vapour drive



4.8.3 Vapour permeable materials

There is considerable potential for confusion in the Australian market for anyone seeking membranes or other building materials with verified levels of water vapour permeance or water vapour resistance.

AS 4200.1:2017 identifies four classifications of water vapour barriers, ranked from Class 1 to Class 4 according to their vapour permeance.

Alert

The permeability and vapour resistance of materials should be considered in the context of their application as highly permeable materials are not always the most suitable solution. Permeance values are usually provided in the units of µg/N.s or MN.s/g.

The designer, architect or engineer should be able to provide guidance on what is appropriate for the application.

4.9 Risk assessment calculation methods and software

The assessment of condensation risk in buildings remains a developing field. The approaches on offer are generally divided between steady state and transient methods although they share a common focus on diffusion as the main means of water vapour movement through the building fabric and include capacity to model risk of accumulation, and capacity to remediate. The use of these methods and associated tools require specialist expert input and interpretation of results. Experienced users should be sought to provide meaningful simulations.

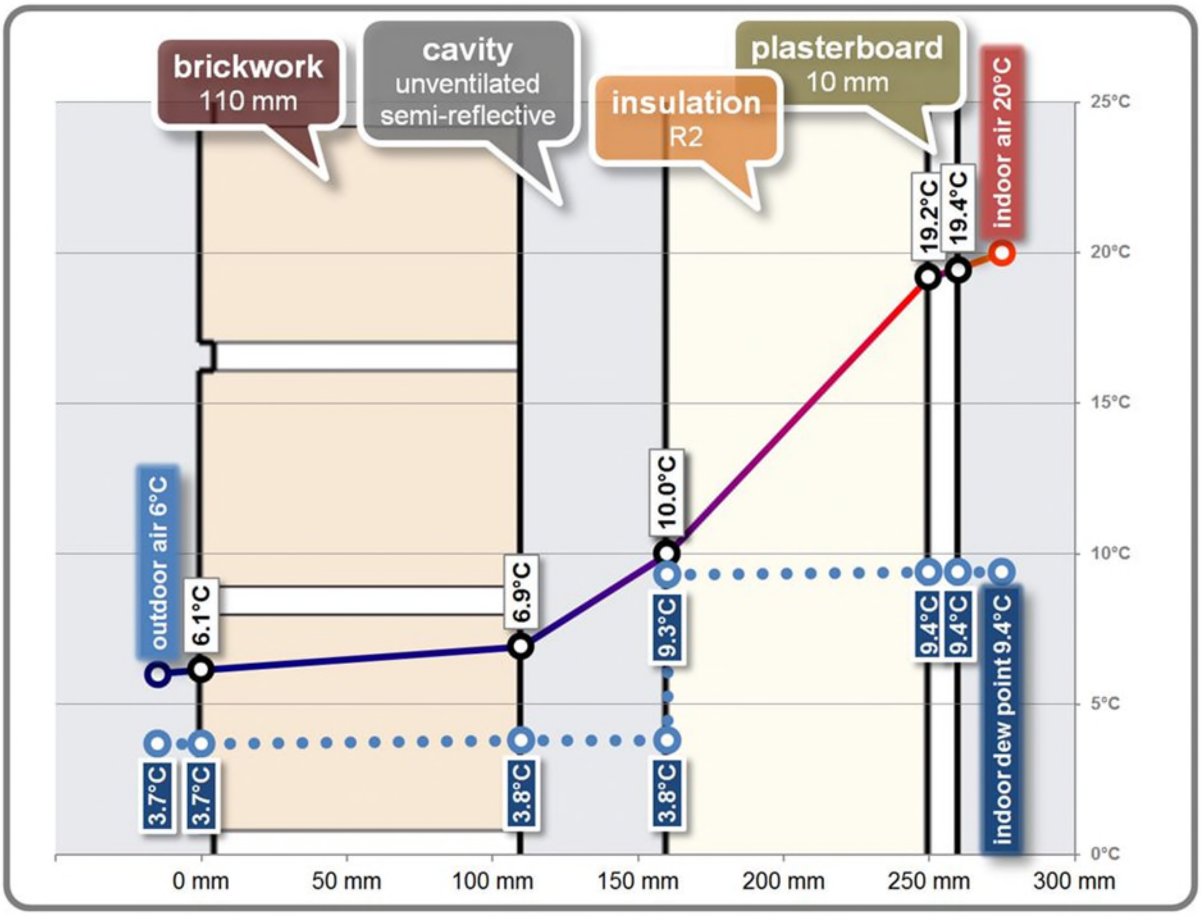
4.9.1 Steady state methods

Steady state methods track the diffusion of water vapour through the materials and spaces of a building envelope, comparing its changing dew point with the temperature of surfaces it encounters along the way. The water vapour follows a simple one-dimensional path and its dew point declines in proportion to the water vapour resistance of the materials it diffuses through.

“Steady state” refers to the assumption that indoor and outdoor air temperatures and dew points can reasonably be considered to maintain their average levels during the period being reviewed. The most common convention is to consider monthly average conditions, accumulating results over the course of a typical year.

Calculations using the steady state approach are simple enough to be done by hand and can also be prepared and presented graphically, to show analogous temperature and dew point (or partial water vapour pressure) gradients through the building assembly (Figure 4.16).

Figure 4.16 Steady state comparison of temperature and dew point gradients across a wall (Note: Assumes a wall wrap with an exterior anti-glare coating provides the semi-reflective cavity)



4.9.2 Transient conditions methods

So called transient methods of risk assessment attempt to represent the complex reality of the climate and the way building materials respond to flows of heat, water and water vapour. While the steady state method considers only the conduction of heat and the diffusion of water vapour, transient methods aim to account for multiple variables under conditions which are realistic for the indoor and outdoor climates and the initial state of the building fabric. These variables include wetting by liquid water, storage of heat and moisture in materials, temperature effects of evaporation and condensation and changes in material properties with temperature and humidity (among other matters).

These ambitions mean the methods involve computer models and simulations which, nevertheless, still provide only a one-dimensional view through the building envelope. The two-dimensional models which are available are generally limited to specialised investigations because of the computer processing power and time needed to run them.

The scope of transient method calculations means that extensive data is needed on climate characteristics and material properties and reliable results depend on a good understanding of building physics and the implications of input choices. Given that most of these developments have occurred overseas, they may lack relevant Australian climate databases and this should be considered when using these tools.

What the steady state and transient methods share in common is the inability to deal directly with air leakage and the water vapour transported in it.

Within their acknowledged limitations, these tools are being extensively developed and calibrated against the lessons of accumulating experience. Properly applied by knowledgeable operators, they can provide useful insights to the persistence of adverse combinations of indoor and outdoor conditions, the comparative benefits of differing constructions and the long term and seasonal behaviour of the building envelope.

For more information regarding this standard refer to Appendix E and Appendix F of this handbook, referring to: British Standard BS EN 15026:2007; and Straube and Schuhmacher, 2006 respectively.

5 Design, construction and occupant checklists

5.1 Design checklist

5.1.1 Climate analysis

- Understand the outdoor climate that acts on the building.

  As a first step, use the map in Appendix D.1 to see how closely outdoor temperatures can approach the dew point of the atmosphere in the locality in the worst-case month (the basis of the coloured regions on the map is described in Section 3.3.3). Any propensity for condensation outdoors can point to outdoor climatic conditions that will make management of indoor water vapour levels more demanding.

  For a complete month-by-month view, prepare the graphical analysis described in Section 3.3.4, using BOM data and the basic psychrometric chart in Figure D.14. Note particularly, the overall daytime conditions in the months when the outdoor minimum temperatures approach or fall beyond the saturation line of the psychrometric chart. High maximum daytime temperatures can suggest that overnight condensation inside the building envelope may not persist to accumulate into problematic amounts.

- Understand the indoor climate of the building, taking account of known activities and sources of water vapour (worst case allowances will need to be assumed where the building occupancy is uncertain or likely to change significantly over time).

  In a building ventilated by outdoor air (the only known source), without dehumidification, indoor water vapour levels will inevitably be higher than those outdoors.

  In the case of a residential building, the graphical climate analysis described in Section 3.3.6 allows a basic assessment of the impact of the indoor climate on likely interstitial condensation risk. If there are any indications of problems using this test, undertake more detailed analysis using conditions for the specific indoor climate of the building.

- Identify the effective boundaries between the indoor and outdoor climates formed by the intended locations of control layers in the envelope and determine the critical temperatures to use for preliminary checking of interstitial condensation risk in the envelope.

  For a quick and approximate check of condensation potential in ventilated sub-floor spaces with floor insulation above, compare the average outdoor dew point temperature for each month with the annual average outdoor temperature. The outdoor annual temperature is a proxy for the ground temperature in the sub-floor space, which will influence temperatures of the coldest surfaces. The monthly average outdoor dew point temperature indicates the water vapour content of the outdoor air used to ventilate the sub-floor space. If the average outdoor dew point temperature is higher than the average outdoor temperature, there is potential for condensation.

For a quick and approximate check on persistent condensation potential in ventilated wall cavities during the heating season, compare the outdoor mean monthly temperature with the indoor dew point temperature. The outdoor temperature approximates (for this purpose) the surface temperature at the exterior face of an insulated stud frame exposed to a cavity ventilated by outdoor air. Using the indoor dew point temperature provides a worst-case test of indoor air leaking through interior linings or control planes to make contact with any membrane on the "cold" side of stud frame insulation. If the indoor dew point temperature is higher than the average outdoor mean monthly temperature, there is potential for condensation.

5.1.2 Designing the building envelope

- Confirm the water vapour resistances of all layers making up a proposed building envelope assembly (floor, wall or roof). Identify the layer with the greatest resistance and ensure that all other layers have resistances substantially lower and declining outwards across the assembly. This will indicate if the assembly has potential to dry (by diffusion and evaporation) to either the interior or to the exterior of the building or, preferably, in both directions.
- Check that the surface temperature of any wall wrap or sheathing on the exterior face of an insulated stud frame remains higher than the indoor dew point in any month when the indoor dew point falls to or below the outdoor mean monthly temperature. Take account of any insulation on either side of the surface, including any inherent thermal resistance available through reflective surfaces facing still air spaces.
- Heated water systems installed within a subfloor space should have adequate ventilation.
- Gas boiler or heated water system should be flued to the exterior of the building fabric, including installations in non-habitable spaces, garages, subfloor zones and roof spaces.

- Bathroom, laundry and kitchen mechanical ventilation should be installed with the flue beyond the exterior skin of the building (wall or roof).
- Use condensing clothes dryers or externally flue them.
- Air-conditioning ducting requires complete enclosure by ceiling insulation product.

5.1.3 Communicating the condensation control strategy

- Convey intent of moisture control strategy to the builder and follow its implementation throughout construction. The advice should cover the strategies, materials, essential performance data and detailing which are intended to avoid both interior surface condensation and interstitial condensation. For surface condensation, the advice might mention how to avoid thermal bridging across framing members, which can cause local cooling of the interior linings. For interstitial condensation, the emphasis might be on how to minimise air leakage and the installation of membranes or sheet materials with specified upper or lower limits for resistance to water vapour transmission.
- Communicate the purpose and intended performance of any membrane or sheet material installed anywhere between the interior lining and the exterior cladding. Communicate which layers can have penetrations for wiring, piping or other services, brick ties, soffit bearers and the like, and which must not have penetrations. Separate layers might be specified where it seems that one would do. Communicate to the builder why this is proposed, and install materials for the control layers only according to the designer's confirmed intention.
- Document the implemented strategy, including any changes needed during construction and convey its essential elements to building users.
- Make moisture management easier for building users (by providing extraction at source wherever possible and building in trickle ventilation).

5.2 Construction checklist

5.2.1 Confirming design intent before construction

- If the designer has not already provided the information, ask for advice on which parts of the design are critical to avoiding condensation and why they matter. The advice should cover the strategies, materials, essential performance data and detail which are intended to avoid both interior surface condensation and interstitial condensation. For surface condensation, the advice might mention how to avoid thermal bridging across framing members which can cause local cooling of the interior linings. For interstitial condensation, the emphasis might be on how to minimise air leakage and the installation of membranes or sheet materials with specified upper or lower limits for their resistance to water vapour transmission.

- The strategy might involve separate layers of materials to control the movement of liquid water, air, water vapour and heat through the building's exterior enclosure. Understand the designer's intent and clarify any uncertainties. Confirm the purpose and performance requirements of any membrane or sheet material installed anywhere between the interior lining and the exterior cladding. Confirm which layers can have penetrations for wiring, piping or other services, brick ties, soffit bearers and the like, and which must not have penetrations. Separate layers might be specified where it seems that one would do. Clarify why this is proposed and install materials for the control layers only according to the designer's confirmed intention.

  Different approaches might be intended for roofs, walls and floors and even in different parts of these building elements where the construction varies from one place to another. For example, a timber clad, timber framed section of wall might be treated differently from a portion with metal or tile exterior claddings.

  In tropical climates or alpine climates, the condensation control strategy might involve membranes or sheet materials with a specified water vapour permeance. Materials with a different permeance should not be used without the designer's agreement. The intended location should be verified specifically with the designer in each case.

5.2.2 Maintaining design intent during construction

- Communicate details of the condensation control strategy to the workers on site who will be involved in implementing it and installing critical materials. It is equally important to advise other trades (particularly services installers) who might unintentionally disrupt a condensation control strategy by making penetrations where they should be avoided or installing unintended materials for other purposes.
- In the construction program, sequence wet construction and finishing trades, such as slab and screed laying, plastering, plasterboard jointing and tiling, to allow the longest possible drying time before enclosure or the application of finishes.
- Do not substitute, add or remove materials without confirming with the designer, the impact on the condensation control strategy. Increasing insulation or a waterproofing material for "extra protection" might have unintended, damaging consequences. Be

sure that the designer provides clear specifications for the performance of materials critical to condensation control and do not supply alternatives selected by generic type. Products which would not be classified as vapour permeable by AS 4200.1, for example, are often marketed as 'breather' membranes, highlighting that product naming and labelling is an unreliable indicator of performance and can lead to damaging results.

- Alert the designer to unexpected sources or quantities of groundwater identified during site formation and excavation and obtain instructions on measures to prevent its accumulation against the building base or under it.
- Protect materials from wetting before they are installed. They will need protection from rain, from damp rising from the ground and from surface water flows. They may need protection from condensation dripping from a sheltering roof or from tarpaulins placed over materials stored on uncovered ground.
- Do not install wet materials and protect installed materials from rainfall, dew and wet building operations once they are in place.
- If materials become wet, allow them to dry before enclosing them any further. This is particularly important for materials which absorb water such as fibrous insulation materials, plasterboard, brick, concrete block, timber and wood products.
- Ensure that ventilation pathways called for in the design remain unobstructed (particularly where they could be blocked during installation of insulation) and are clear at the time of handover. Ensure that weepholes, which may also serve as ventilation openings for wall cavities, remain clear.
- Open any trickle ventilation provided by the designer and other secure means to ventilate the interior until handover and especially when the building is locked up overnight during construction. Provide additional temporary fixed or mechanical ventilation or dehumidification when needed, especially where signs of surface condensation in the interior are present.

5.2.3 Communicating condensation control strategy at handover

- Before handover, advise the building users about the need for drying of construction moisture during the first year or more of occupation.
- Alert building occupants to any facilities provided for fixed ventilation, such as trickle ventilators in window frames, and for extracting water vapour directly from showers and other indoor sources. Outside the building, point out ventilation openings to any

sub-floor space, wall cavities or roof space and the importance of avoiding accidental obstruction through building up of garden beds and overgrowing plants or creepers.

5.3 Occupancy checklist

- The comments and suggestions here apply mainly to homes and are for people dealing with condensation problems or who suspect they may be. Not every Australian home is at risk of the issues discussed. The map in Figure 3.26 (and enlarged in Appendix D.1) highlights regions where outdoor conditions become cold enough, in at least one month of an average year, to cause water vapour in the air outdoors to condense into dew or mist. This event is undramatic in itself but points to climatic conditions that can contribute to problems with high RH or condensation indoors. In most cases, those problems can be avoided by simple choices householders can make in day-to-day activities.
- In a new or renovated building, expect that the first year or more may need closer attention to dealing with moisture indoors than in later years when building materials have had time to dry to normal levels. Frequent ventilation and extra heating will assist with drying but some processes cannot be hurried. A concrete floor slab, for example, dries at the rate of about 25 mm of depth per month. Using fans or heaters to accelerate drying affects only the surface layer. A 100 mm thick slab needs about four months to dry and a 150 mm slab can take more than twice that time. Applying finishes or laying floor coverings over damp concrete may cause bubbling of adhesives, mould growth under carpets, increased release of formaldehyde or the breakdown and staining of plasticisers in vinyl flooring.
- During the first winter of use, expect that a new house or apartment might require more heat than it will need in later winters.
- Be alert to condensation forming on the glass and frames of windows. These are usually the coldest surfaces in a room and condensation on them is an early warning of high RH that can support dust mite infestations and mould growth. Condensation may form on metal window frames before it appears on the glass. It is likely to be noticed first on the glass of timber framed windows and doors but can be occurring unseen on timber frames which are able to absorb it. At a given RH level, condensation will tend to form less readily on double glazed windows and doors, although it may already be at unwelcome levels in the room. Surface condensation of this sort should always be wiped up to discourage mould growth or decay of timber frames, window sills or architraves. Even painted timber can absorb water left to sit

and the paint will be at risk of bubbling or flaking when the water later evaporates. As well, avoidable sources of water vapour in the affected rooms should be looked for and eliminated as far as possible.

- Open windows or doors periodically for efficient and cost-effective natural ventilation which will reduce the amount of water vapour circulating indoors. In cooler seasons, opening windows in the afternoon, when daytime temperatures are highest, will limit the impact of the cooler outdoor air on the temperature inside. The free flow of air through windows and doors can also reduce air movement that would otherwise leak through minor gaps and cracks in the building enclosure, carrying water vapour to concealed parts of the construction and cause hidden mould or condensation problems. Condensation in many insulating materials will reduce their resistance to the flow of heat and increase running costs for the building.
- To avoid high RH and to minimise the risk of condensation, in a building showing signs of problems, notice which activities release water vapour indoors (Section 3.3.5) and reduce their output as far as possible. This need not mean substantially curtailing the activities. Capturing water vapour from cooking, from bathing and showering, from washing and drying clothes by the use of exhaust fans ducted directly to the outdoors can largely reduce the impact of these activities on indoor water vapour levels.

  To operate effectively, rooms with exhaust fans running need to draw air from other rooms or passageways or through open windows or doors. The fans need to have a capacity suitable for the size of the rooms and to run long enough to restore safe levels of RH. Fans with timer switches or humidity sensors are available to ensure effective clearing of water vapour. When installing ducted exhaust systems, take care that the outlet of a duct or flue does not discharge under eaves or overhanging floors which could allow the water vapour to find its way into other parts of the building.

  Running exhaust fans draws in some outdoor air (even if the effect is not obvious inside the room). In cooler seasons, outdoor air arriving this way will generally be drier than air indoors and can help to dilute water vapour levels inside. By contrast, in warm humid climates and weather, outdoor air drawn in by exhaust fans carries unwanted water vapour and running times should be restricted in these situations when air-conditioning is being used for cooling.

  A stove or oven fuelled by gas, will release water vapour from the burning of gas and needs closer attention to location near windows or venting arrangements. It is important to note that recirculating range hoods do not capture or remove water vapour given off by cooking but return it to the room with, possibly, fewer odours.

- When planning the layouts of storage rooms, built-in cupboards or cabinets, remember that water vapour leaks and diffuses through apparently solid walls and can accumulate where air circulation is low and the wall surface is shielded from heating. Avoiding stores and cupboards against external walls is advisable, especially on south facing walls and those on the leeward side of a building, in climates showing a potential for condensation. If cupboards must be fitted on external walls, the walls should be well insulated, without thermal bridges, and ventilation gaps should be formed at the back of the cupboards.
- When positioning freestanding furniture, avoid placing large items against outside walls as far as possible and always leave space for air to circulate on all sides. This applies especially to wardrobes and cupboards used to store leather shoes or garments which are particularly susceptible to mould growth.
- When heating is needed for comfort, it will have the greatest effect on lowering RH and condensation risk if it is applied continuously and through all interior spaces at an even temperature. Rooms left unheated might accumulate enough water vapour to reach the 70% RH level that makes mould viable.
- Many small portable heaters aim only to provide local comfort for somebody sitting in a heated airstream or facing a radiant element. They will have limited effect on air temperature in the room where they are being used and less on overall air temperatures and RH in a home.
- Although generalised heating has a beneficial effect in lowering RH (section 3.2.5), reducing the release of water vapour from indoor sources should be the first priority.
- When planning alterations or additions to a house, investigate what provisions were originally made to minimise the risk of condensation and (assuming they have been proven by experience) consider carrying them through to the new construction. Where documents or advice about the original building are not available, consider whether the roof space was deliberately ventilated or made as airtight as possible, whether efforts have been made to seal around cables and pipes passing through linings, whether sheet materials or membranes have been installed inside walls, under the roof or floor to control the movement of air or water vapour.
- Be cautious about inserting downlights, exhaust fans and other openings through ceilings that previously had no openings to the roof space because they may break down deliberate protection against air leakage. Sealed light fittings should be used wherever their installation cannot be avoided.
- When using air-conditioning in summer, avoid the temptation to pre-chill an unoccupied homes for a cooler return. The suggestions above about maintaining

general and even heating levels do not apply to the use of air-conditioning for cooling. Turning off air-conditioning in empty rooms will allow the temperature to rise and potentially adverse (damaging) RH to fall.

- Seek informed advice when selecting an air-conditioning system and confirm that it has the capacity to control both temperature and humidity. Many systems sold on the basis of a simple room area calculation, without an understanding of local climatic conditions, cannot provide the dehumidification needed to avoid surface condensation. Although the difference between indoor and outdoor summer temperatures can be smaller in Darwin than in Melbourne, an air-conditioner in Darwin has almost four times the total amount of cooling to do, largely due to a dehumidification requirement in Darwin being about 80 times greater than in Melbourne.
- Use condensing clothes dryers or externally flue them.

Appendices

Appendix A Acronyms

The following table, Table A.1, contains acronyms used in this document.

Table A.1 Acronyms

Acronym	Meaning
ABCB	Australian Building Codes Board
ACH	air changes per hour
AIRAH	Australian Institute for Refrigeration, Air conditioning and Heating
ANSI	American National Standards Institute
AS	Australian Standard
AS/NZS	Australian Standard/New Zealand Standard
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
ASTM	American Society for Testing and Materials
BAL	Bushfire Attack Level
BAL-FZ	Bushfire Attack Level – Flame Zone
BCA	Building Code of Australia
BOM	Bureau of Meteorology
BS EN	British Standard European Standard
DA	Design Application (i.e. AIRAH's DA Manuals)
DTS	Deemed-to-Satisfy
HVAC	heating ventilation and air-conditioning
IGA	inter-government agreement
ISO	International Standardization Organisation
NCC	National Construction Code
RH	relative humidity
UK	United Kingdom
US	United States
VCM	vapour control membrane
WHS	Workplace Health & Safety

Appendix B Compliance with the NCC

B.1 Responsibilities for regulation of building and plumbing in Australia

State and territory governments are responsible for regulation of building, plumbing and development/planning in their respective state or territory.

The NCC is a joint initiative of the Commonwealth and State and Territory Governments in Australia and is produced and maintained by the ABCB on behalf of the Australian Government and each state and territory government. The NCC provides a uniform set of technical provisions for the design and construction of buildings and other structures and plumbing and drainage systems throughout Australia. It allows for variations in climate and geological or geographic conditions.

The NCC is given legal effect by building and plumbing regulatory legislation in each state and territory. This legislation consists of an Act of Parliament and subordinate legislation (e.g. Building Regulations) which empowers the regulation of certain aspects of buildings and structures and contains the administrative provisions necessary to give effect to the legislation.

Each state's and territory's legislation adopts the NCC subject to the variation or deletion of some of its provisions, or the addition of extra provisions. These variations, deletions and additions are generally signposted within the relevant section of the NCC and located within appendices to the NCC. Notwithstanding this, any provision of the NCC may be overridden by, or subject to, state or territory legislation. The NCC must therefore be read in conjunction with that legislation.

B.2 Demonstrating compliance with the NCC

Compliance with the NCC is achieved by complying with the NCC Governing Requirements and relevant Performance Requirements.

The Governing Requirements are a set of governing rules outlining how the NCC must be used and the process that must be followed.

The Performance Requirements prescribe the minimum necessary requirements for buildings, building elements, and plumbing and drainage systems. They must be met to demonstrate compliance with the NCC.

There are three options available to demonstrate compliance with the Performance Requirements. These are:

- a Performance Solution
- a Deemed-to-Satisfy Solution, or
- a combination of a Performance Solution and a Deemed-to-Satisfy Solution.

All compliance options must be assessed using one or a combination of Assessment Methods, as appropriate. These include:

- Evidence of Suitability
- Expert Judgement
- Verification Methods
- Comparison with DTS Provisions.

A figure showing hierarchy of the NCC and its compliance options is provided in Figure B.1. It should be read in conjunction with the NCC.

To access the NCC or for further general information regarding demonstrating compliance with the NCC visit the ABCB website.

Figure B.1 Demonstrating compliance with the NCC

Appendix C Glossary

C.1 NCC defined terms

NCC definitions for the terms used in this handbook can be found in Schedule 1 of NCC 2022 Volumes One, Two and Three.

C.2 Other terms

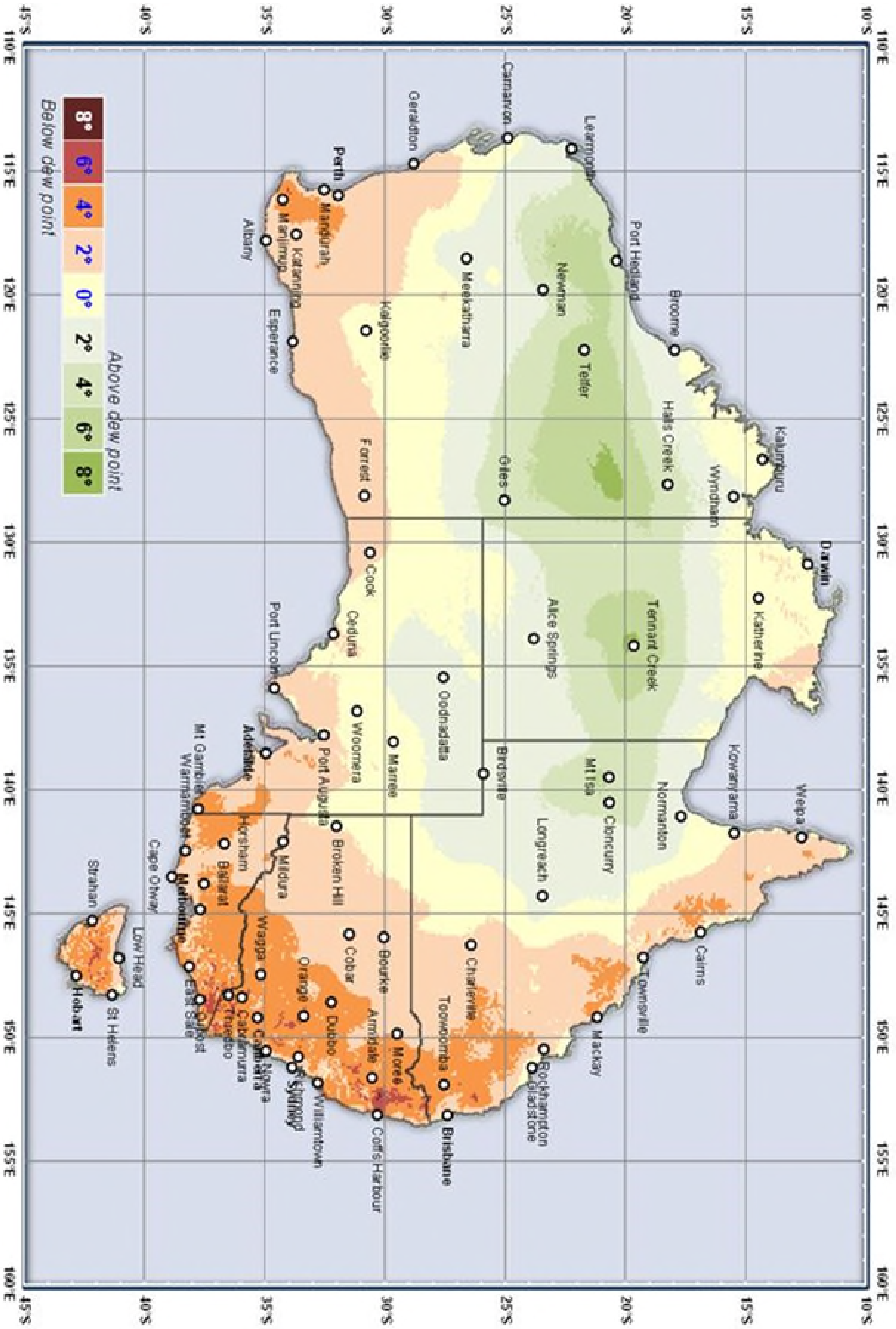
- **Air barrier**: A layer that prevents the movement of air under the normal pressure differences found across building elements.
- **Building fabric**: The materials and systems used for the construction of a building which includes, but is not limited to, insulation, cladding, glazing and roofing material.
- **Dew point**: The temperature at which the RH of the air reaches 100%, at which time saturation occurs and water vapour contained in the air will begin to condense. The dew point temperature of the air depends upon the air temperature and the humidity of the air and can be determined using a psychrometric chart.
- **Dry bulb temperature**: A measure of the temperature of the air, excluding the influence of radiation and moisture. Together with wet bulb temperature, RH and dew point at the ambient temperature can be determined.
- **External moisture**: The penetration of moisture into the building cavity through various sources (i.e. rain, capillary action, leaks, solar driven moisture, air movement and vapour diffusion).
- **External side**: The weather side of a building material or membrane (i.e. the surface of a material or membrane closest to the exterior of the building).
- **Hygroscopic materials**: Materials with the ability to absorb moisture from the air.
- **Internal moisture:** Moisture generated by human activities inside a building (i.e. breathing, sweating, cooking, clothes drying or showering).
- **Internal side**: The room side of a building material or membrane (i.e. the surface of a material or membrane, closest to the interior of the building).
- **Microclimate**: The unique local climate which is measurably different to the general climate of the region.

- **Psychrometric chart**: A chart of the physical properties of moist air for a particular altitude or air pressure. It can be used to determine the dew point temperature and moisture content of air for a defined set of conditions.
- **Relative humidity (RH)**: The measure of the amount of water vapour in the air relative to the maximum amount of water that the air can hold at a given temperature.
- **Surface condensation**: Surface condensation takes place on the surface of a body when the temperature of the surface is less than the dew point temperature of the surrounding warm moist air.
- **Thermal conductivity**: A measure of the ability of a material to conduct heat.
- **Thermal resistance**: A measure of the ability of a material to resist heat transfer.
- **Vapour barrier**: Vapour impermeable layer or material used to restrict the transmission of vapour, generally water vapour, either into a building or from inside into the cavity of the building fabric.
- **Vapour diffusion**: The result of vapour pressure difference between indoor and outdoor air conditions. The rate of diffusion depends upon the permeability of the linings and materials that make up the building fabric.
- **Vapour permeable membrane**: A membrane intended to allow the transmission of water vapour. This is often referred to as a breathable membrane or breathable underlay.
- **Vapour resistance**: A measure of a material's reluctance to let water vapour pass through. The reciprocal of vapour permeance.
- **Vapour resistivity**: The resistance to water vapour of a homogenous body per unit thickness. The reciprocal of vapour permeability.
- **Wet bulb temperature**: Wet-bulb temperature reflects the physical properties of a system with a mixture of a gas and a vapour, usually air and water vapour. Wet bulb temperature is the lowest temperature that can be reached by the evaporation of water only. It is the temperature felt when the skin is wet and is exposed to moving air.

Appendix D Supplementary material

D.1 Map of outdoor overnight condensation potential

Figure D.1 Map of outdoor overnight condensation potential (enlarged Figure 3.26)



Notes for Figure D.1

Section 3.3.4 outlines the method used to construct the map in Figure D.1 (an enlarged version of Figure 3.26). The map relies on values calculated by the ABCB from gridded datasets of minimum temperatures and 9am and 3pm dew point temperatures generated by BOM. It is acknowledged, however, that the comparison between mean minimum temperatures and average dew points is not a recognised climate index and the resulting map cannot be endorsed by BOM.

BOM prepared the gridded datasets at a cell resolution of 0.1° or about 10 km per side. The data records extended from 1981 to 2010. The Bureau attaches the following qualification to the gridded datasets it supplies:

> *The analyses (grids) are computer generated using a sophisticated analysis technique. .... This grid-point analysis technique provides an objective average for each grid square and enables useful estimates in data-sparse areas such as central Australia. However, in data-rich areas such as southeast Australia or in regions with strong gradients, "data smoothing" will occur resulting in grid-point values that may differ slightly from the exact temperature measured at the contributing stations.*

D.1.1 Assessment of the impact of indoor water vapour loads

Figure D.2 provides examples of the graphical analysis introduced in Section 3.3.6. The climate locations covered here represent the most populous regions in each NCC climate zone or are situated within state or territory capital cities.

Figure D.2 Water vapour content values adjusted for indoor load – Darwin (NT)

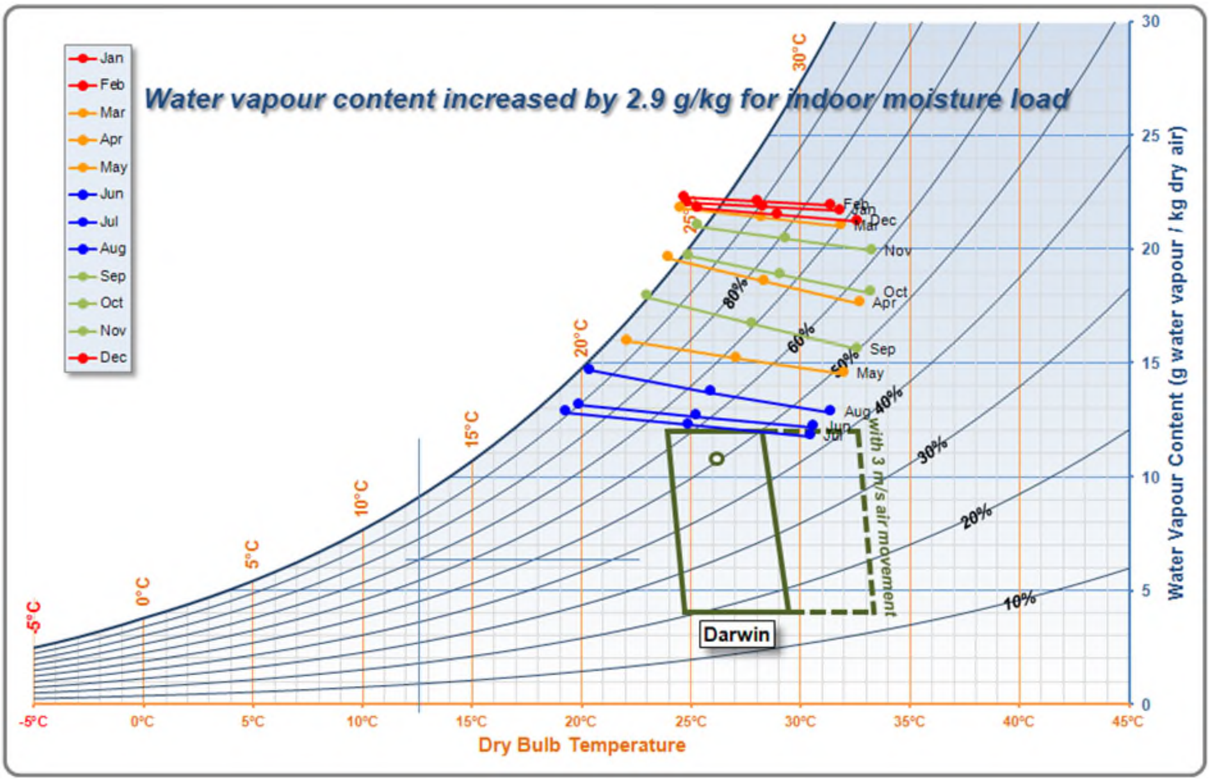


Figure D.3 Water vapour content values adjusted for indoor load – Townsville (Qld)

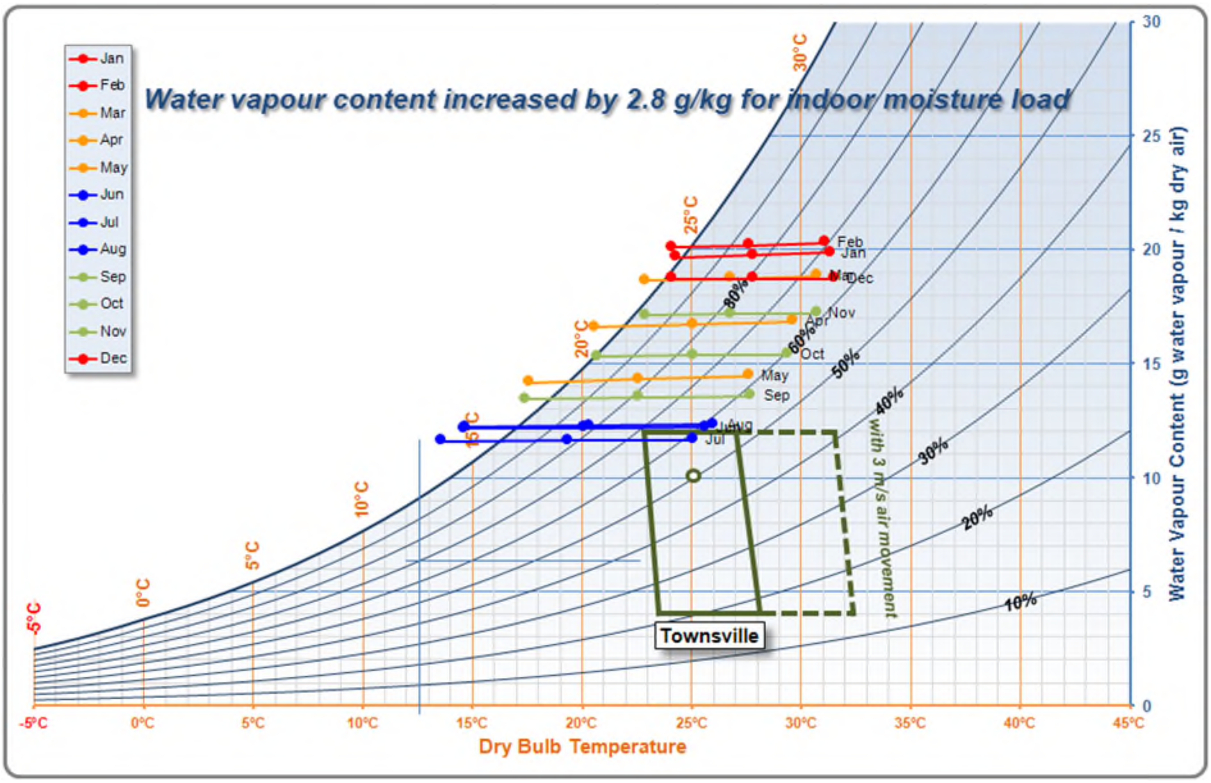


Figure D.4 Water vapour content values adjusted for indoor load – Brisbane (Qld)

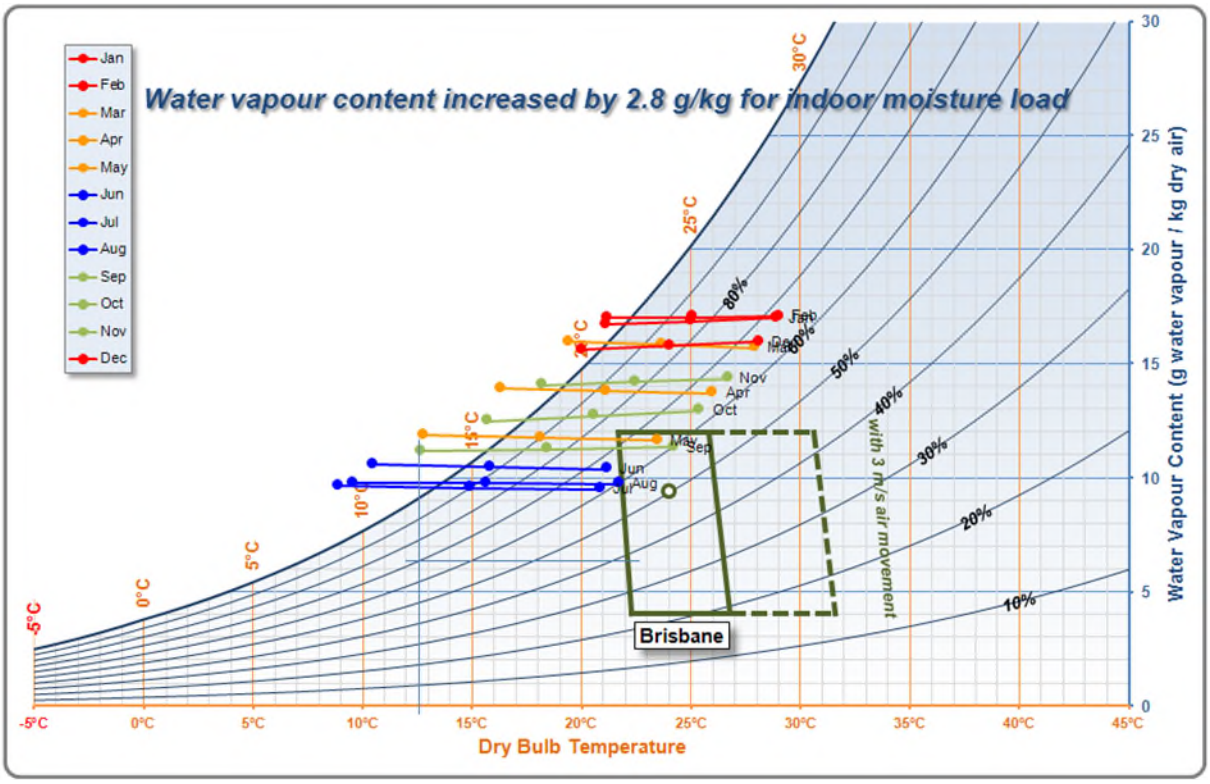


Figure D.5 Water vapour content values adjusted for indoor load – Longreach (Qld)

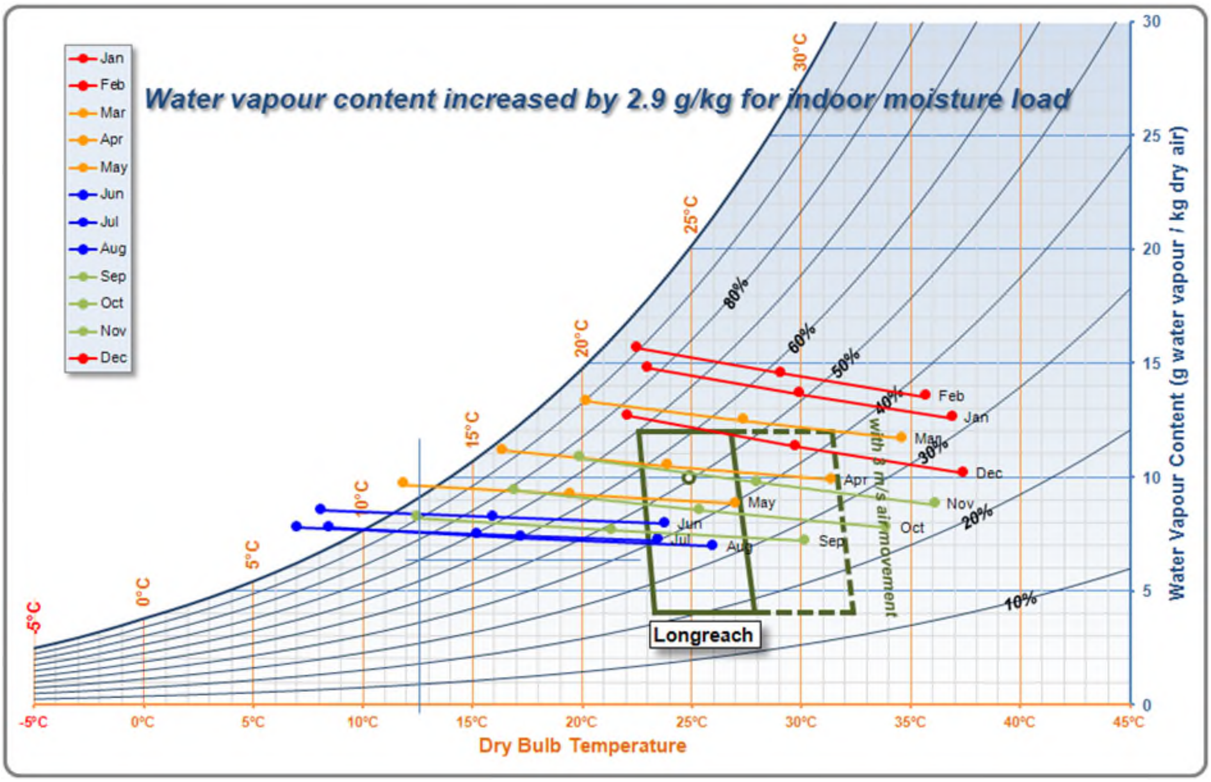


Figure D.6 Water vapour content values adjusted for indoor load – Mildura (Vic)

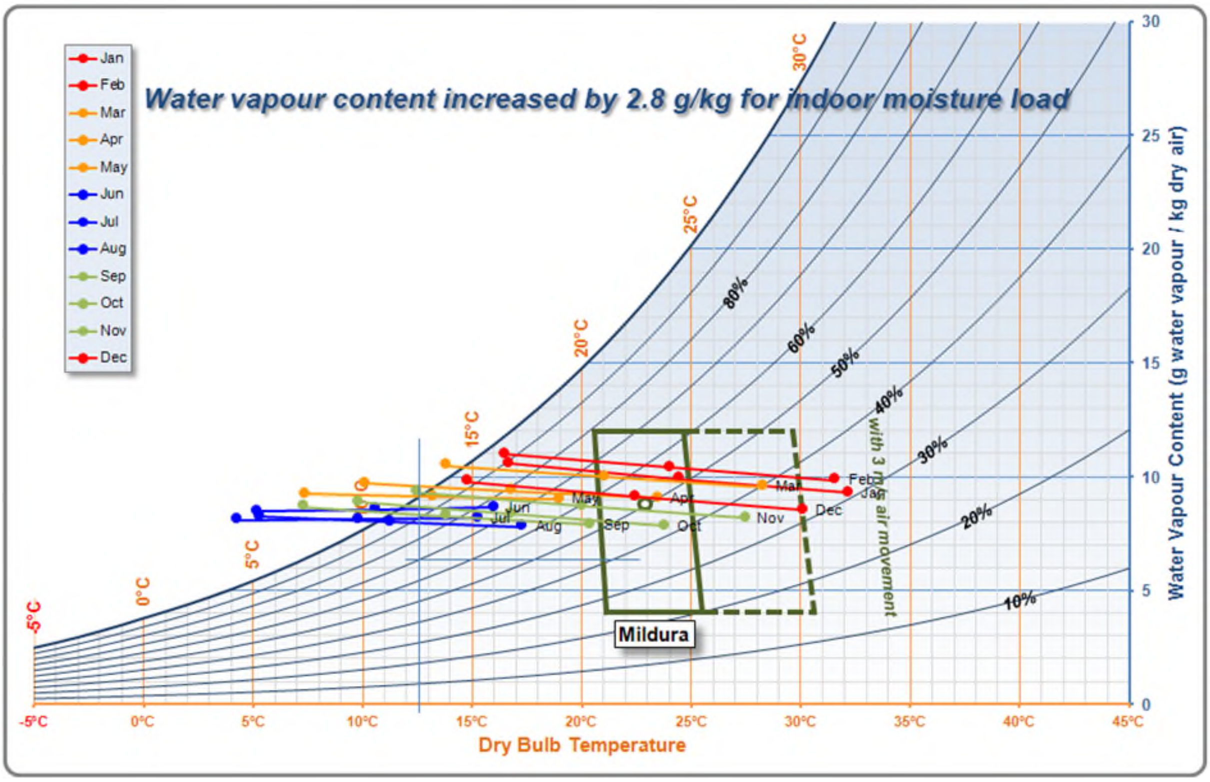


Figure D.7 Water vapour content values adjusted for indoor load – Perth (WA)

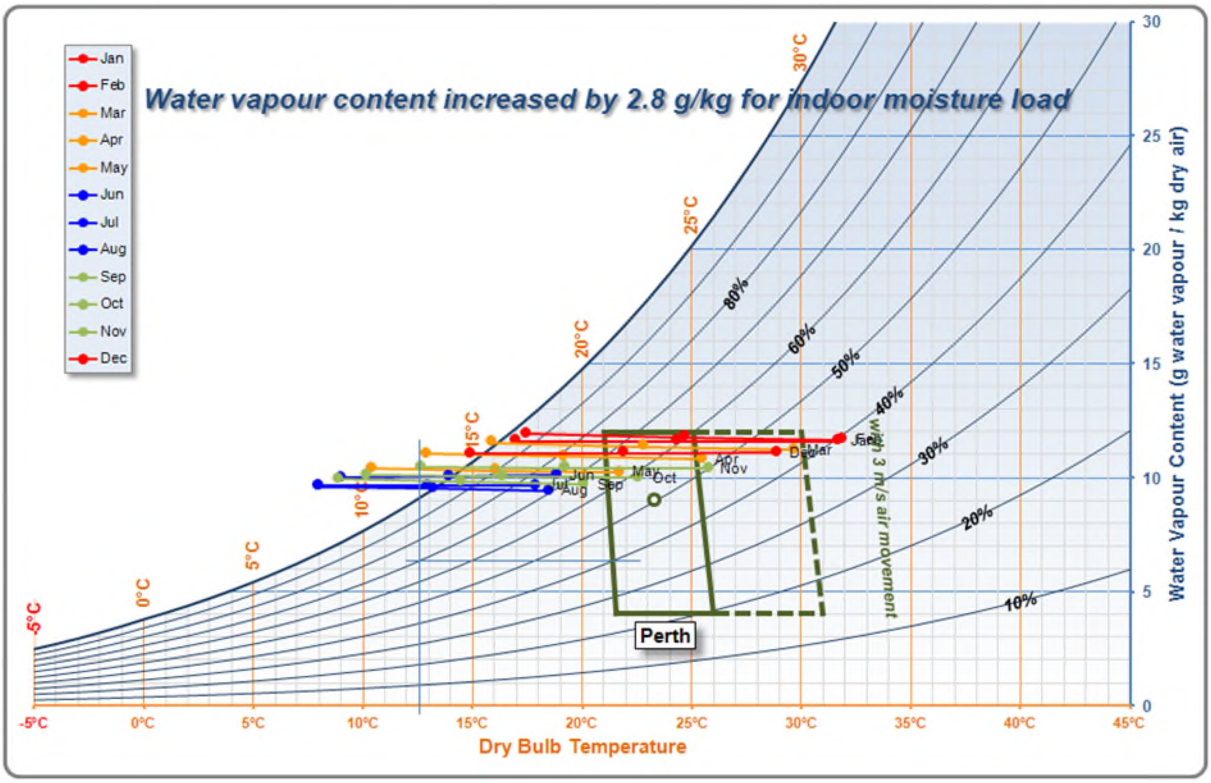


Figure D.8 Water vapour content values adjusted for indoor load – Adelaide (SA)

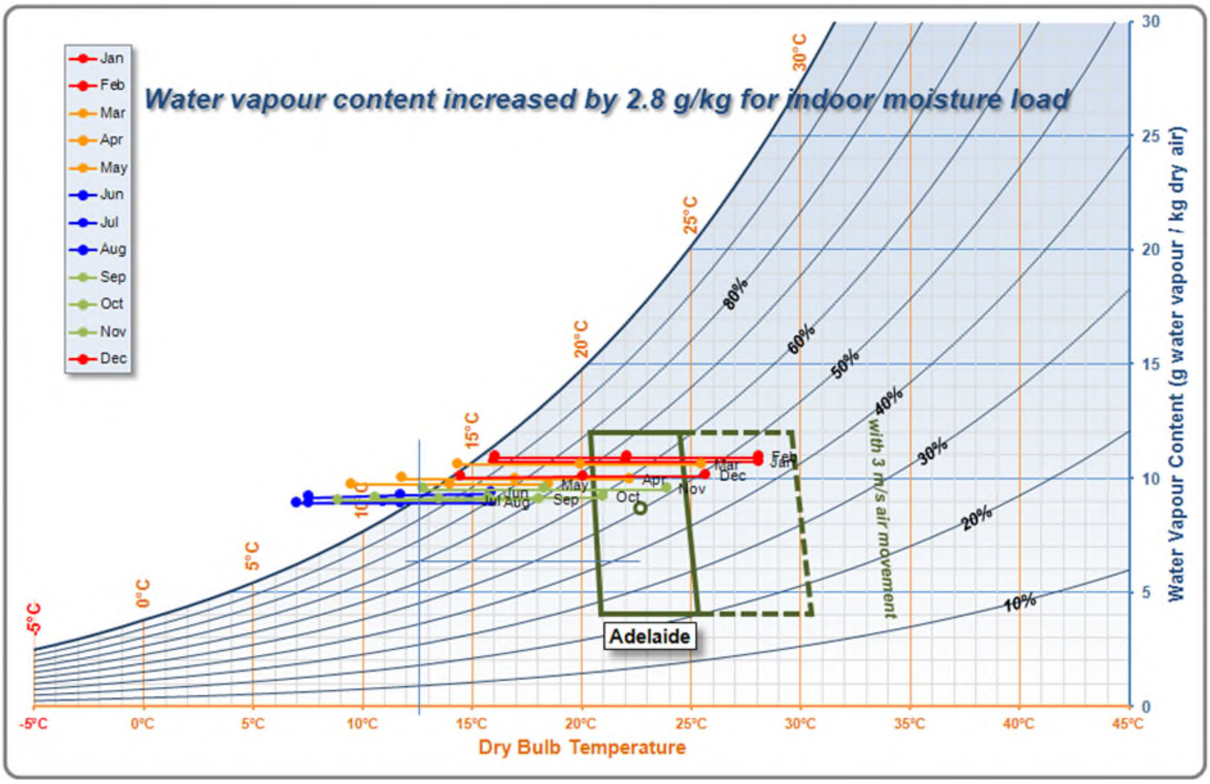


Figure D.9 Water vapour content values adjusted for indoor load –Mascot, Sydney (NSW)

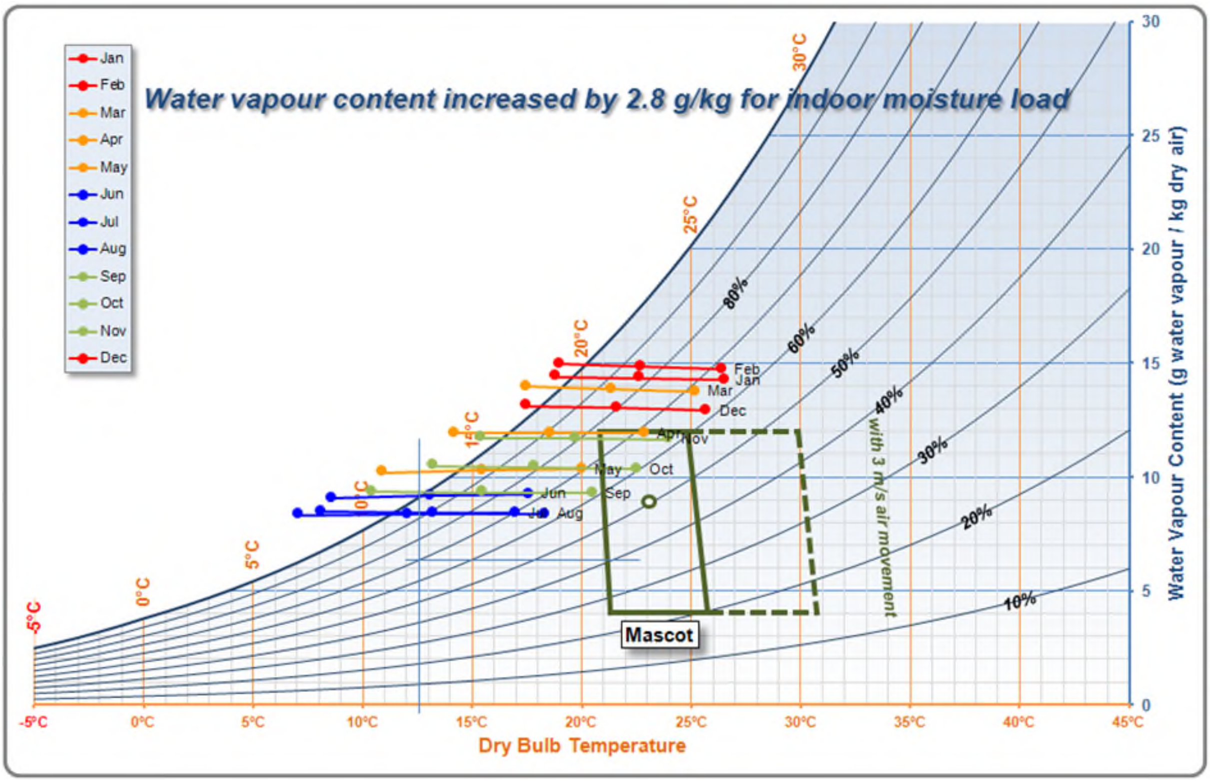


Figure D.10 Water vapour content values adjusted for indoor load – Moorabbin, Melbourne (Vic)

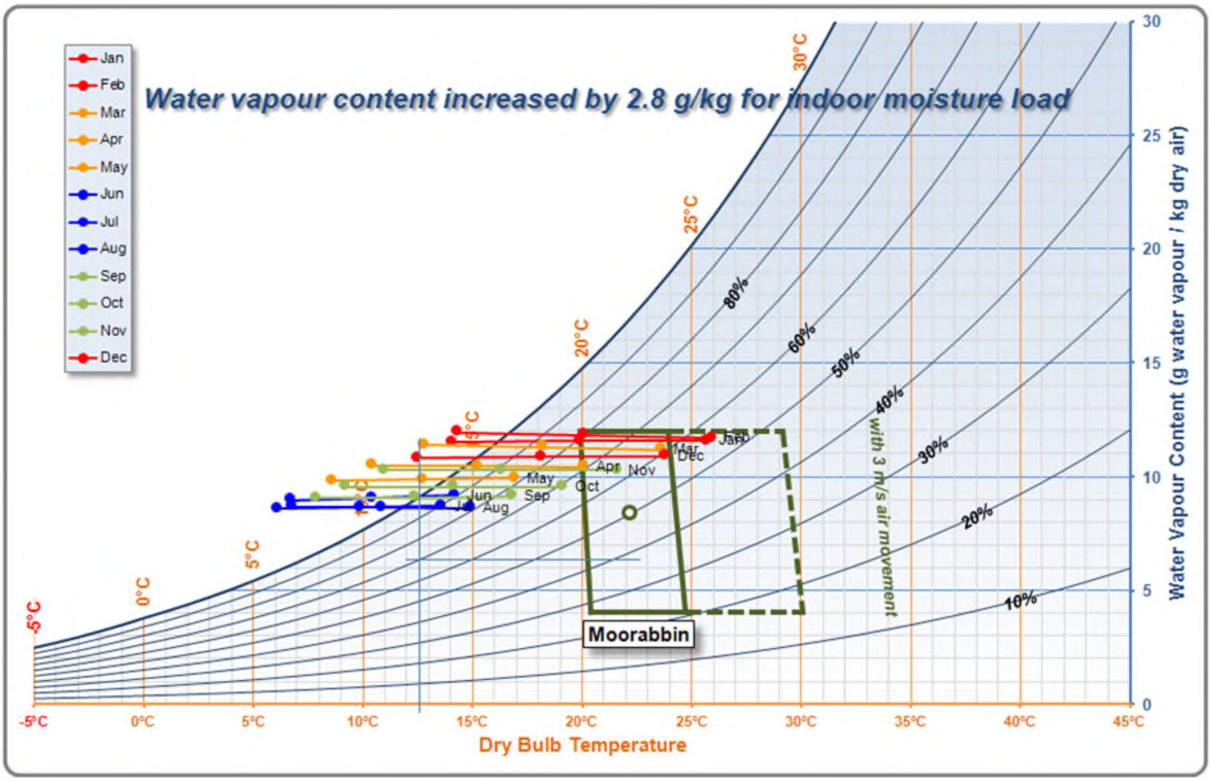


Figure D.11 Water vapour content values adjusted for indoor load – Canberra (ACT)

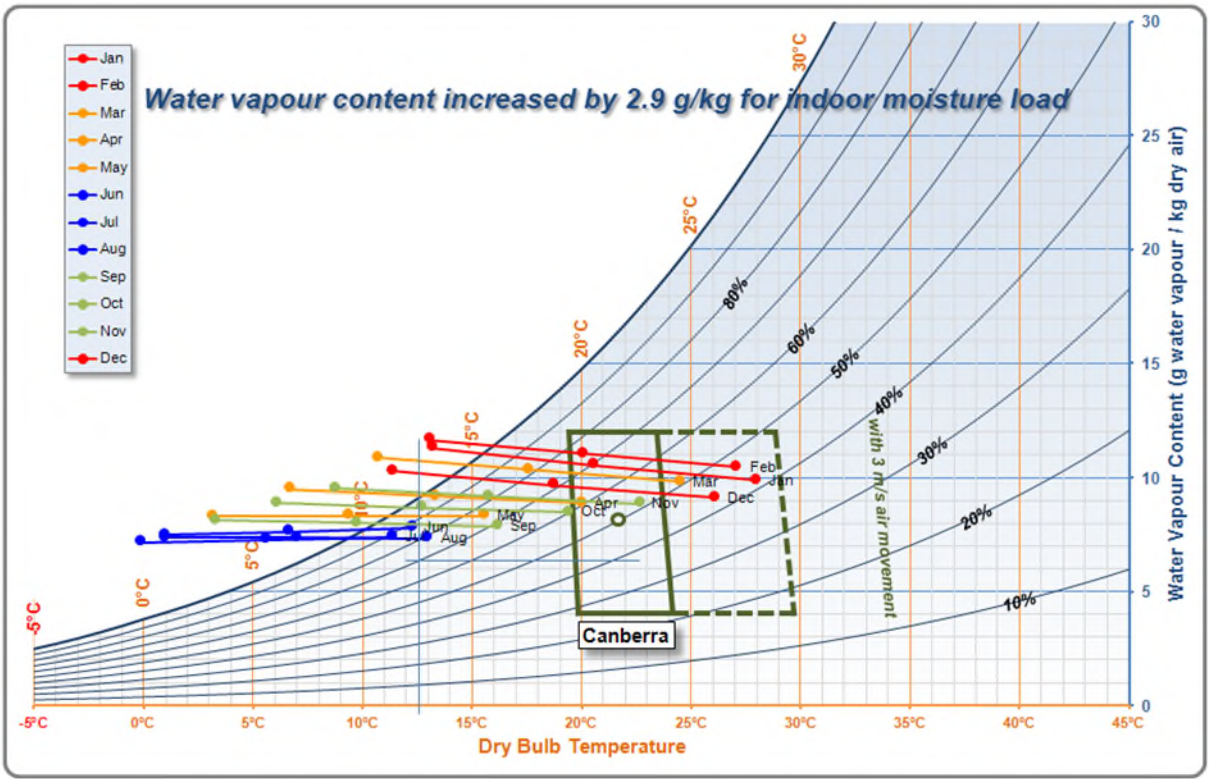


Figure D.12 Water vapour content values adjusted for indoor load – Hobart (Tas)

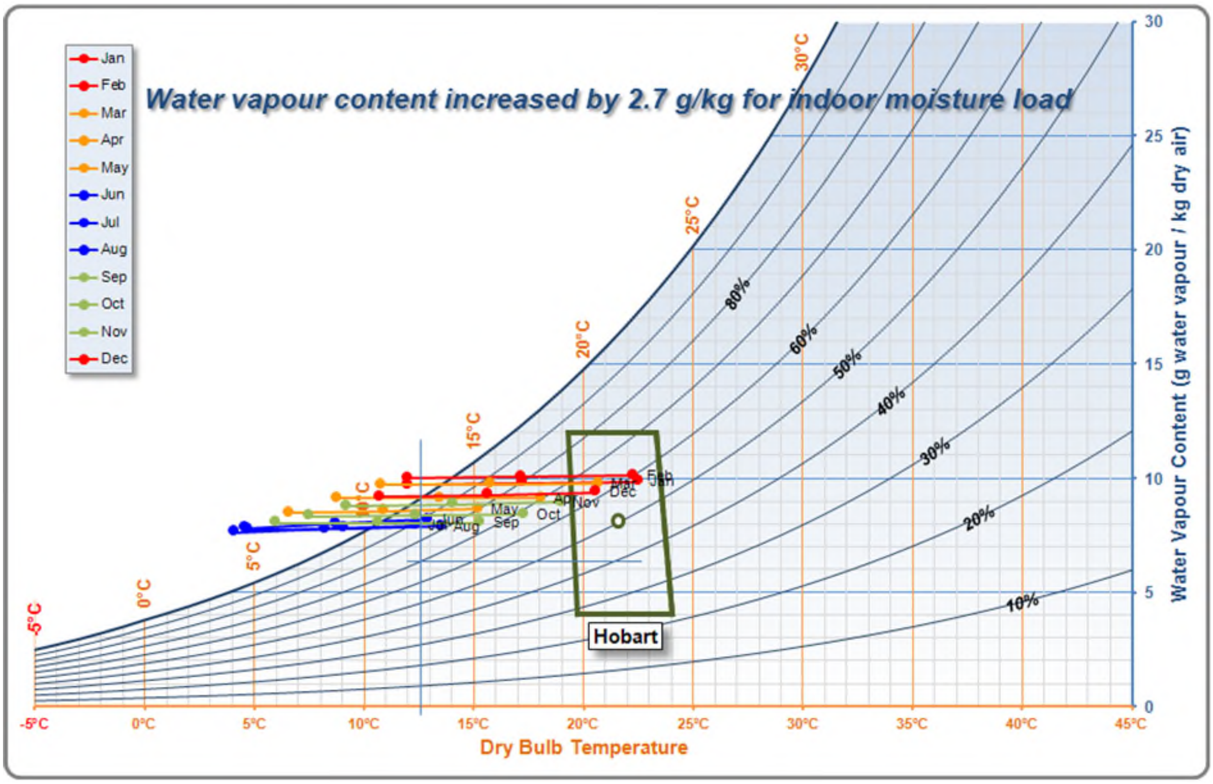
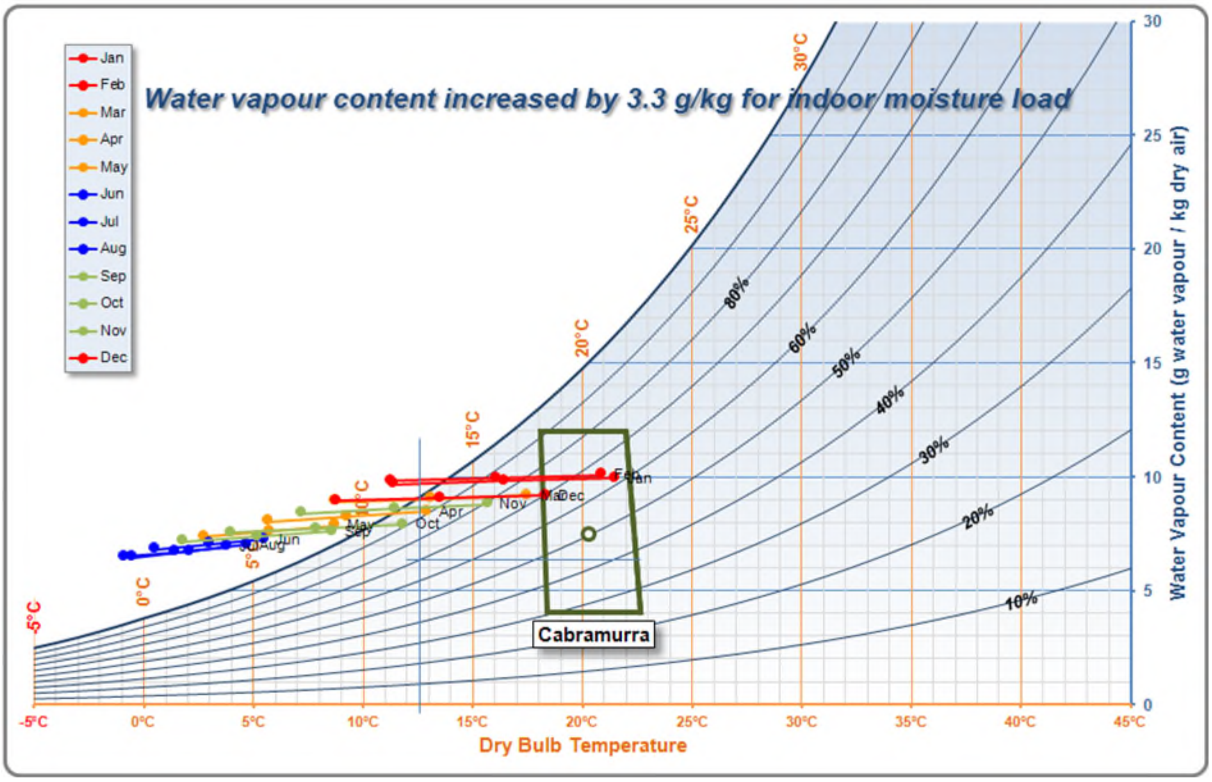
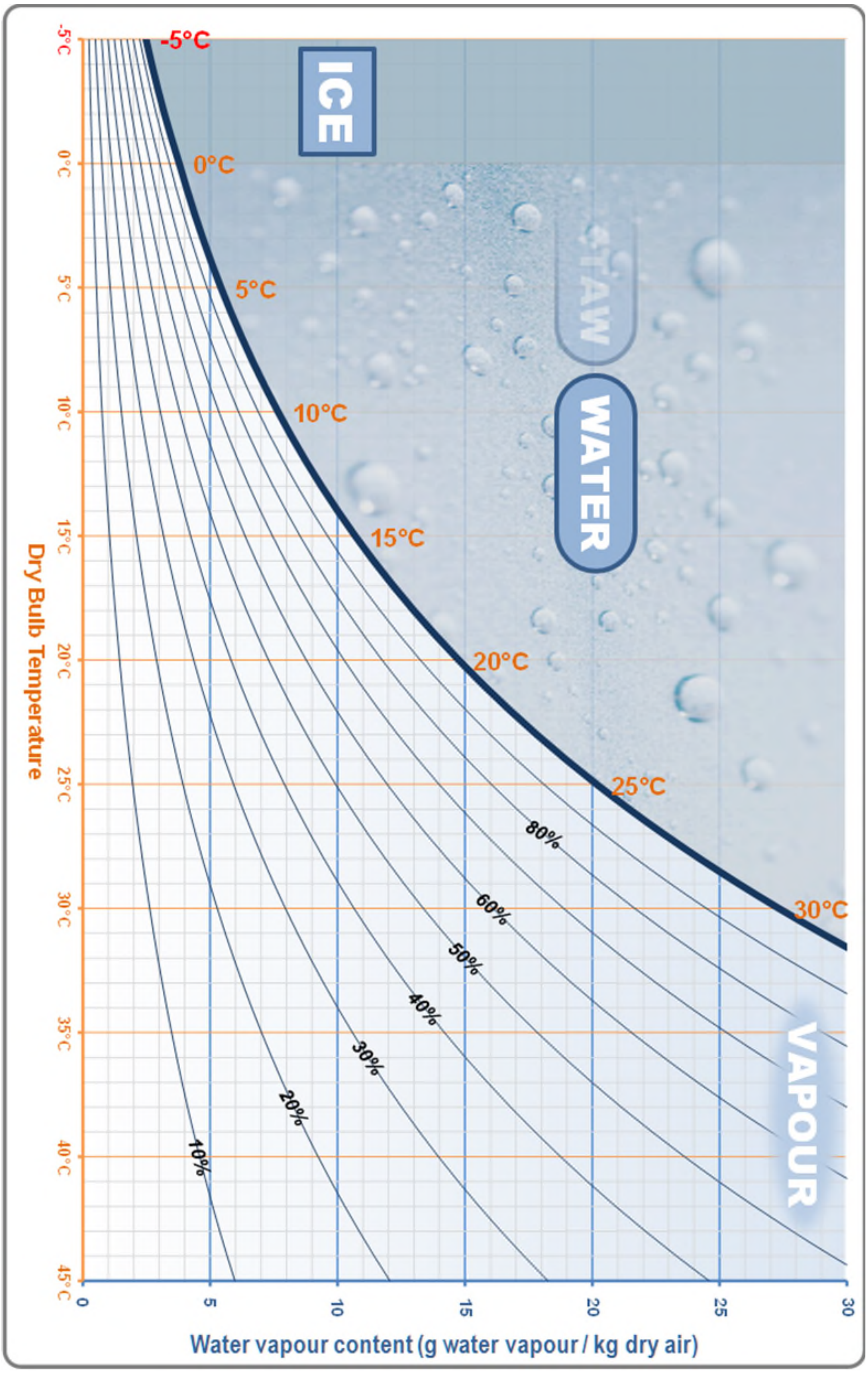


Figure D.13 Water vapour content values adjusted for indoor load – Cabramurra (NSW)



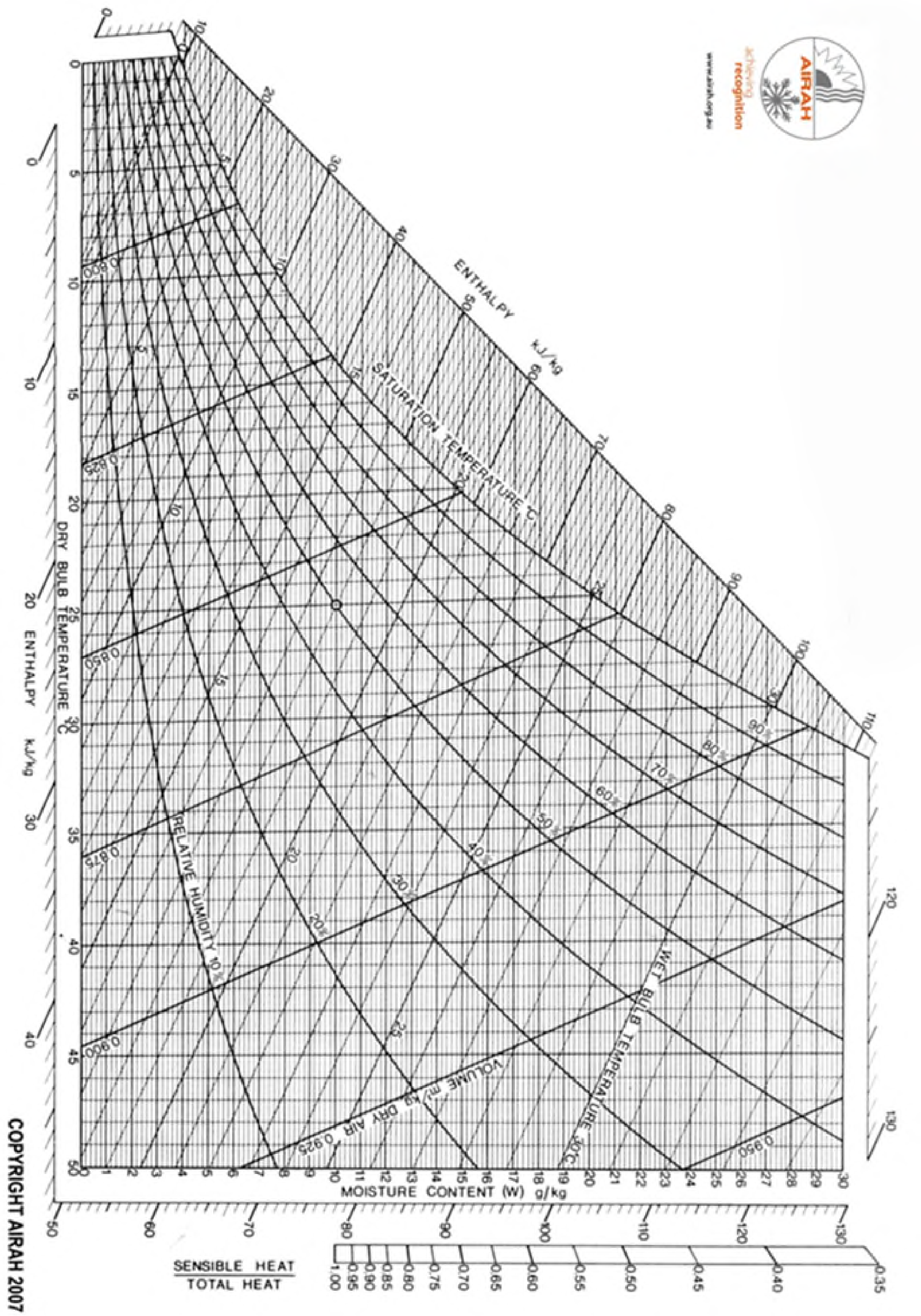
D.1.2 Basic psychrometric chart

Figure D.14 Basic psychrometric chart for climate analysis



D.1.3 Standard psychrometric chart

Figure D.15 Standard psychrometric chart at sea level supplied by AIRAH



Appendix E Standards

This appendix covers key Australian and International Standards as they relate to condensation. There is no Australian Standard that solely deals with the management of condensation. However, standards dealing with roofing, wall cladding, insulation, masonry, and bushfire management, all affect how designers and builders deal with issues that affect condensation.

There are International Standards that address condensation specifically. These standards are aimed at European climate zones and often use very different construction practices not common in Australia. For these reasons designers need to be wary of blindly following International Standards.

E.1 Australian Standards

Referenced documents adopted through the NCC include Australian Standards which may influence approaches to envelope design or offer guidance on condensation issues. Summaries below describe the scope and purpose of some of these documents and briefly outline their content dealing with condensation matters. Other standards, not referenced in the NCC but with content relevant to condensation issues, are similarly covered.

Usage of the terms “vapour barrier” and “vapour retarder” in the standards differ in some cases from their wider application in building science literature. Since these and other terms may also vary between standards, their definitions should be checked in each document.

E.1.1 Design and installation standards

AS 1562.1:2018 Design and installation of sheet roof and wall cladding - Part 1: Metal

This Standard sets out requirements for the design and installation of self-supporting metal roof and wall cladding, subjected to out-of-plane loading, such as wind loads.

NCC Volume One refers to this Standard to determine the structural resistance of metal roofing in non-cyclonic areas in Part B1 and it forms part of the DTS Provisions for roof coverings in Part F3. References in NCC Volume Two occur in H1D7 where AS 1562.1 satisfies Performance Requirement H1P1 for metal roof and wall cladding.

The Standard has a non-mandatory Appendix A, titled Roof Ventilation, Water Vapour and Condensation. It notes that condensation can occur in all types of buildings, largely due to poor design or inappropriate use of materials and, once present, it is difficult to eliminate". The Appendix also discusses the impact of night sky cooling on roof surface temperatures and the limitations on ventilation in low pitch roofs, which both increase condensation risk. Comments concerning vapour barriers (used with and without bulk insulation) point out that any barrier should be correctly placed to "prevent water vapour from reaching the cold surface".

AS 1562.2:1999 Design and installation of sheet roof and wall cladding - Part 2: Corrugated fibre-reinforced cement

The Standard is intended for use by manufacturers, specifiers and installers of corrugated fibre-reinforced cement roof and wall cladding in domestic, commercial and industrial applications. It covers requirements for corrugated fibre-reinforced cement sheeting, fasteners, seals and safety mesh, as well as issues in design and installation.

Alert

This Standard is not referenced in the NCC.

Condensation risks and responses are discussed in the informative (non-mandatory) Appendix A - Guidance Notes on Roof Ventilation in two parts: Condensation (A1) and Vapour Barriers (A2). Appendix A1 advises that "climatic conditions in many parts of Australia are such that condensation [on the underside of roofing] may occur.

Appendix A2 also advises that "water vapour from any source whatsoever should not be vented into the roof space". It recommends inclusion of an impermeable vapour barrier in the roof system "placed on the underside ('warm' side) of the roof lining, as far removed from it as practicable. Any separate insulating material should be above (on the 'cold' side) of the vapour barrier and should not be in direct contact with the sheeting". The commentary in A2 does not mention that "above" the vapour barrier will be the warm side for an air-conditioned building in a warm humid climate. Appendix A2 refers, as well, to sealing around openings in ceilings for light fittings and flues to prevent water vapour entering the roof space and notes that adequate ventilation should be provided between roof sheeting and impermeable insulating materials to permit the evaporation of condensate.

AS 1562.3:2006 Design and installation of sheet roof and wall cladding - Part 3: Plastic

This Standard sets out procedures for the design and installation of plastic roof and wall cladding materials and is primarily intended to apply to those materials complying with the AS 4256 Plastic roof and wall cladding suite of standards.

NCC Volume One refers to AS 1562.3, along with AS 4597, in F3D2. NCC Volume Two refers to AS 1562.3, in Part H1D7. Unlike Parts 1 and 2 of the AS 1562 standard series, Part 3 does not comment on condensation issues.

AS 2050:2018 Installation of roof tiles

This Standard sets out the requirements for the placement and installing of roof tiles (specified in AS 2049) and includes sarking requirements. Pliable building membranes (or underlays) and reflective foil laminates are also mentioned. A pliable building membrane may act as a sarking membrane, thermal insulation, a vapour barrier or any combination of the three. Both pliable sarking and reflective foil laminates are required to comply with AS 4200 Parts 1 and 2.

NCC Volume One refers to this Standard in Part F3 for the fixing of concrete roof tiles in non-cyclonic areas. In Part H1D7 of NCC Volume Two, AS 2050 satisfies Performance Requirement H1P1 for tiled roof cladding.

Although there is no direct reference to condensation within the Standard, sarking requirements, which may affect the configuration of the roof cladding and the approach to managing water vapour movement, are included.

In applying these requirements of the Standard, it is important to note that the sarking must be able to fulfil its defined waterproofing role but need not, necessarily, act as a vapour barrier or as thermal insulation. Suitable material properties in these contexts should be considered separately as part of condensation control.

AS 4773.1:2015 Masonry in small buildings - Part 1: Design

This Standard provides minimum requirements for the design and specification of masonry in Class 1 and Class 10a buildings. It covers unreinforced and reinforced masonry construction, as well as built-in components. A companion document,

AS 4773.2, provides simplified details for the construction of the masonry.

NCC Volume Two refers to AS 4773.1 and AS 4773.2 in the DTS Provisions of Part H1D5 as satisfying Performance Requirement H1P1 for masonry veneer.

The resistance to moisture penetration for masonry is addressed in AS 4773.1 through weather-resistant coatings and damp-proof courses to prevent rainwater and groundwater penetration through the masonry into the structure. Although condensation is not explicitly referred to in this Standard, the restriction of moisture penetration through the masonry may help to reduce condensation risk.

E.1.2 Insulation and building membranes

AS/NZS 3999:2015 Thermal insulation of dwellings—Bulk insulation: Installation requirements

This Standard deals with the installation of bulk thermal insulation in all classes of dwellings. It provides both specific and general requirements for installation and includes safety requirements. Condensation assessment is considered in Section 2, Pre-installation Inspection and Procedures. This section highlights the need for insulation to be selected and installed in accordance with the design specification, which may include vapour control membranes, air barriers or additional ventilation to reduce the potential for condensation. The Standard also provides guidance for when vapour barriers, vapour permeable membranes or air barrier membrane are already installed or are intended to be installed, stating that the following factors shall be assessed:

(a) The design specification shall clearly state where the bulk insulation is to be installed in relation to any vapour barriers located within the construction system.

(b) The type of bulk insulation shall be clearly stated in the design specification with adequate information to enable the installer to select the insulation in accordance with Clause 3.2.3 of AS 3999:2015.

(c) Whether the building designer has considered condensation risk.

Alert

This Standard is not referenced in the NCC.

Additional information regarding condensation can be found in Appendix G. This informative appendix covers topics such as: moisture issues; Internal and external moisture; the mechanisms of moisture movement; and condensation risk assessments.

This standard highlights the importance of a condensation risk assessment calculation when designing well-sealed buildings, for energy efficiency, acoustics or bush fire resistance. The standard states that: “condensation risk analysis can be carried out in accordance with ISO 13788 or conducted using an hourly analysis software program using weather conditions consistent with approved energy rating software. This assesses the risk of condensation within any configuration of cladding, air cavities, membranes, insulation, internal linings or any other additional construction layers.

AS 4200.1:2017 Pliable building membranes and underlays - Part 1: Materials

This Standard sets out the requirements for materials suitable for use as a pliable building membrane (also known as an underlay) in various circumstances. Pliable building membranes may serve as sarking, thermal insulation and vapour barriers, or for any combination of these uses. From a moisture management perspective, the Standard provides classification of water barriers, vapour barriers and the absorbency of pliable building membranes.

NCC Volume One refers to this Standard in F3D3 and F8D3 where sarking-type materials and pliable building membranes used for weatherproofing roofs and walls are required to comply with AS 4200 Parts 1 and 2. Likewise, NCC Volume Two refers to this Standard in H2D6 where sarking is required to comply with AS 4200.1. 10.8.1, condensation management in the Housing Provisions, requires the pliable building membranes to comply with AS 4200.1 and be installed in accordance with AS 4200.2.

This Standard sets the minimum requirements for the material properties of pliable building membranes and does not discuss condensation.

AS 4200.2:2017 Pliable building membranes and underlays - Part 2: Installation requirements

This Standard is a companion document to AS 4200.1 and sets out the installation procedures for pliable building membranes. An informative (non-mandatory) Appendix C provides details on protection against condensation.

NCC Volume One refers to this Standard in F3D3 and F8D3 where sarking-type materials and pliable building membranes used for weatherproofing roofs and walls are required to comply with AS 4200 Parts 1 and 2. Likewise, 10.8.1 for condensation management in the Housing Provisions requires the pliable building membranes to comply with AS 4200.1 and be installed in accordance with AS 4200.2.

This standard highlights the increased risks associated with condensation when thermal control membranes are installed over rather than under roof battens.

Appendix C highlights that condensation is a very complex problem which can occur under a variety of conditions, not just cold conditions. The Appendix provides advice about the need to place the pliable building membrane/material in the correct location based on the environment and its intended use. It also covers topics such as: moisture issues; Internal and external moisture; the mechanisms of moisture movement; and condensation risk assessments.

AS/NZS 4859.1:2018 Materials for the thermal insulation of buildings - Part 1: General criteria and technical provisions

This Standard specifies requirements and methods of test for materials that are added to, or incorporated in, opaque envelopes of buildings and building services, including ductwork and pipework, to provide thermal insulation by moderating the flow of heat through the envelope and building services. The types of insulation materials covered by this Standard include cellulose fibre insulation, insulation containing wool, low density polyester fibre insulation, low density mineral wool insulation and reflective insulation. Guidance on installation of insulation is provided in AS 3999 and AS 4200.2. Reflective insulation with a prime function as a sarking or vapour barrier is covered by AS 4200 Parts 1 and 2.

NCC Volume One refers to the Standard in the DTS Provisions of J4D3, J6D6 and J6D9 for the testing of insulation materials, as does Housing Provisions in 13.2.2, 13.7.2 and 13.7.4.

This Standard deals with consistent testing and performance evaluation of thermal insulation and does not discuss condensation related matters.

E.1.3 Bushfire prone areas

AS 3959:2018 Construction of buildings in bushfire-prone areas

This Standard is primarily concerned with improving the ability of buildings in designated bushfire-prone areas to withstand attack from bushfire. The measures set out in the Standard state requirements for the construction of a building to improve resistance against burning embers, radiant heat, flame contact and combinations of the three. Construction requirements differ depending on the particular BAL which is a measure of the severity of a building’s potential exposure.

In a designated bushfire prone area, G5D3 in NCC Volume One requires certain residential buildings to comply with AS 3959 in order to meet the DTS Provisions of Part G5. Similarly, H7D4 in NCC Volume Two refers to the same Standard for compliance with Performance Requirement H7P5.

There may be implications for managing condensation risk based on the ventilation and roof construction requirements in this Standard. Restrictions apply to the aperture of ventilation openings and joints in walls and roofs based on the specified BAL. Requirements for sarking in roof and wall elements are also detailed within this Standard based on the BAL.

E.1.4 Hygrothermal analysis

AIRAH Standard DA07: 2021 Criteria for Moisture Control Design Analysis in Buildings

AIRAH Standard DA07, which is adapted from ANSI/ASHRAE Standard 160:2016, seeks to provide a consistent framework for design assumptions or assumed “loads” when using computer simulation tools to predict thermal and moisture conditions in buildings and the building envelope. The Foreword notes that “computer models are increasingly used to make recommendations for building design in various climates. However, results obtained with these models are extremely sensitive to the assumed moisture boundary conditions". It also records that development of the standard "pointed to many unanswered questions, questions that hopefully will be addressed and answered by research in the near future".

AIRAH Standard DA07 is referenced in NCC Verification Methods F8V1 and H4V5, which are optional methods for showing compliance of roof and wall systems with the NCC condensation management requirements. Refer to Section 2.2 for more information.

The content of AIRAH Standard DA07 covers the minimum acceptable criteria for selecting analytical procedures, inputs to those procedures (design parameters), the evaluation and use of the outputs and comprehensive reporting requirements. These requirements are elaborated below:

E.1.4.1 Criteria for design parameters

Comprehensive criteria are provided for the design parameters used as calculation inputs for assessing moisture control in a building. These parameters include:

- initial moisture content of building materials
- indoor temperature, humidity and ventilation rates
- residential moisture generation rates
- air pressure differentials
- weather data requirements
- rain load on walls, and
- rain penetration.

E.1.4.2 Criteria for selecting analytical procedures

The AIRAH Standard DA07 sets minimum acceptable criteria for analytical tools capable of analysing thermal and moisture transfer and conditions in building envelope components. It requires the analytical procedure to be transient with a maximum time step of one hour. To comply with the Standard, as a minimum requirement, the procedure shall have the ability to include:

- energy transport, including temperature effects of phase change
- material properties as a function of moisture content
- water (liquid and vapour) transport by: capillary transport; moisture deposition on surfaces; storage in materials; vapour diffusion; and water leakage.

If the design includes a ventilated cavity, the analysis shall include the effects of the cavity.

The analytic procedure shall provide the following outputs:

- temperature and surface related humidity at each surface and at the interface of the material layers
- average temperature for each material layer
- average moisture content for each material layer.

It is important to note that current transient analytic tools, including the pre-eminent WUFI (from the Fraunhofer Institute for Building Physics), do not account for heat and moisture effects caused by air convection through and within building components, limiting the application of this standard in situations which are not uncommon.

E.1.4.3 Moisture performance evaluation criteria

The quantified performance evaluation criteria provided in the Standard include measures for conditions affecting mould growth and corrosion of the various materials and surfaces within the building or the building envelope, excluding the exterior surface of the building.

E.1.4.4 Reporting

Reporting requirements are specified in the standard and include the following:

- description of assembly
- material data
- building information
- intermediate method reporting
- evaluation criteria, and
- results.

E.1.4.5 Informative annexes

The 4 annexes, which are not necessary for compliance with AIRAH Standard DA07, include flowcharts for moisture-control design using the Standard and for finding indoor design humidity, a commentary on the Standard a bibliography and descriptions of addenda to the ANSI/ASHRAE Standard 160-2009.

E.2 International Standards

There are a number of international standards available that provide details on moisture control and condensation risk assessment in buildings and building envelopes. The summaries below describe the scope of some of these standards and outline the nature of their content.

British Standard (BS) 5250:2011+A1:2016 Code of practice for control of condensation in buildings

This Standard is a code of practice providing guidance and recommendations, rather than prescriptive requirements, on the risks associated with excessive humidity in buildings, notably mould growth and condensation. The Foreword advises that "It should not be quoted as if it were a specification and particular care should be taken to ensure that claims of compliance are not misleading."

The Standard describes the causes and effects of surface and interstitial condensation in buildings and gives recommendations for their control, in the context of British climatic conditions and construction practices. Guidance is provided for designers, builders, building owners and managers and for those occupying buildings with the recommendations covering heating, ventilation and construction and methods to assess the likely occurrence and effects of surface condensation, mould growth and interstitial condensation.

The content of the Standard consists of three key sections and thirteen Annexes and includes designing to avoid moisture-related problems, guidance to builders, owners and advice on remedial works.

The guidance provided on assessing the likelihood of condensation, suggests designers make assessments using the methods described in International Standard ISO 13788, noting its limitations (such as ISO 13788 only considering risks arising from the diffusion of water vapour through the building fabric and not taking into account the much greater risk of condensation as a result of air leakage transporting water vapour through gaps, joints and cracks in the building fabric). Further limitations of International Standard ISO 13788 are also described whereby it does not apply to so-called "cold pitched roofs", where insulation is provided at the ceiling level, limiting heat flow into the roof space from an interior that is presumed to be warmed.

The Standard highlights a preference to use longer term external climate data for condensation risk analysis, as an average year of external climate data does not represent the worst conditions and might result in damaging condensation. A once-in-ten-year climate year for sensitive buildings or a once-in-fifty-year climate year may be more appropriate.

Chapter 4 goes on to discuss other topics such as ventilation, dehumidification, heating, as well as analysis of the external envelope. The external envelope section discusses the placement of thermal insulation and air and vapour control layers. It should be noted that the scenarios discussed may be problematic if applied to particular Australian locations without considering differences in climatic conditions from those the Standard addresses.

Of 13 annexes, A-N, contained in the document; five are normative and deal with the application of cold climate design principles to floors, walls, roofs, ventilation and heating. Other essential design information contained in the annexes includes:

- the essential relationship between temperature and moisture content of air;
- methods of calculating the risk of surface and interstitial condensation;
- typical quantities of moisture generated in buildings of various uses and levels of occupation;
- thermal conductivity and vapour resistivity values of common building materials; and
- factors for conversion of common units.

The informative Annex N offers non-technical guidance for building users and homeowners on the application of the principals discussed in the Standard to minimise the risk of damaging condensation. It covers the basics on how to avoid condensation caused by household use and activities; dehumidification of a building after construction or inundation by water and advice on alterations and extensions to existing buildings.

BS EN 15026:2007 Hygrothermal performance of building components and building elements — Assessment of moisture transfer by numerical simulation

This Standard is the UK implementation of EN 15026:2007. It specifies the equations to be used in a simulation method when calculating the non-steady transfer of heat and moisture through a multi-layer building envelope with fluctuating climates on either side. The introduction to the Standard suggests that, compared to steady-state assessments, "transient hygrothermal simulation provides more detailed and accurate information on the risk of moisture problems within building components and on the design of remedial treatment". While the alternative Glaser method described in ISO 13788 deals only with steady-state conduction of heat and with vapour diffusion, BS EN: 15026 covers transient models which consider heat and moisture storage, latent heat effects and the transport of water as a liquid or by convection, using realistic boundary and initial conditions. Examples of phenomena that models covered by the Standard can simulate include:

- drying of initial construction moisture;
- moisture accumulation by interstitial condensation due to diffusion in winter;
- moisture penetration due to driving rain exposure;
- summer condensation due to migration of moisture from outside to inside;
- exterior surface condensation due to cooling by longwave radiation exchange;

- moisture-related heat losses by transmission and moisture evaporation.

An important qualification on the application of the hygrothermal equations described in the Standard is that they are not to be used where “convection takes place through holes and cracks”. In this context, it should be noted that mandatory air leakage testing in the UK sets an upper limit which may allow air leakage through holes and cracks at rates which would limit the application of this Standard.

In addition, the equations rely on some simplifying assumptions (at variance with actual events), including:

- no swelling or shrinkage of materials to affect geometry;
- no chemical reactions;
- latent heat of sorption matches latent heat of condensation or evaporation;
- no changes to material properties due to ageing or damage;
- local equilibrium between liquid and vapour phases without hysteresis;
- moisture storage does not depend on temperature; and
- vapour diffusion is not affected by gradients in temperature or barometric pressure.

The data for modelling external conditions must be representative of the location of the building but it is noted that “test reference years for energy design [which] are representative of mean conditions may not be appropriate for moisture design”. For a new building, the Standard stipulates using at least one year of external conditions appropriate to the most severe likely location of the building. Ten or more years of measured data is suggested, however, as the most appropriate source.

A non-mandatory Annex B suggests that “a once in ten years failure rate is usually considered to be acceptable” in most moisture applications. It notes, however, that in particularly sensitive applications, such as computer centres, art galleries or hospitals, a lower failure rate might be required. Guidelines for the selection and use of external climate data in targeting specific problems, or buildings requiring operation under constrained conditions are also listed here.

A non-mandatory Annex C provides two charts to determine internal temperature and humidity conditions for “heated buildings (only dwellings and offices) based on external air temperature”. The daily mean of the external air temperature is used to select the appropriate indoor air temperature and the indoor RH. The RH chart offers two curves; one for “normal occupancy” and the other for “high occupancy”. The high occupancy curve matches that used in Figure 4.3.1 of ANSI/ASHRAE Standard 160:2009 for the simplified method of determining design indoor RH.

ISO 13788:2012 Hygrothermal performance of building components and building elements — Internal surface temperature to avoid critical surface humidity and interstitial condensation — Calculation methods

This Standard is a second edition which replaces the first edition, International Standard ISO 13788:2001. It lays down simplified calculation methods which assume that moisture transport is by vapour diffusion alone and use monthly climate data. It deals with:

- surface humidity likely to lead to mould growth on internal surfaces of buildings;
- interstitial condensation within building components during heating periods, cooling periods and in cold stores; and
- estimated drying times after wetting for components located between layers with high water vapour resistance and the risk of condensation occurring elsewhere in the component while drying.

The introduction notes that “in some cases, airflow from the interior of the building into the structure is the major mechanism for moisture transport, which can increase the risk of condensation problems very significantly.” It states that “this International Standard does not address this issue; where it is felt to be important, more advanced assessment methods should be considered”. The introduction concludes by advising that results using the Standard “will be more reliable for lightweight, airtight structures that do not contain materials that store large amounts of water. They will be less reliable for structures with large thermal and moisture capacity and which are subject to significant air leakage”.

Under Scope, the Standard advises that, by accounting only for vapour diffusion, “the method used does not take account of a number of important physical phenomena, including air movement from within the building into the component through gaps or within air spaces. Consequently, the method is applicable only where the effects of these phenomena can be considered to be negligible”. Suitability of this Standard to Australian construction should be assessed on an individual basis as air movement through the building fabric is unlikely to be negligible.

The Standard sets requirements for input data used in calculations, including:

- material and product properties;
- external boundary conditions (including taking account of altitude and the use of monthly mean values for climatic data); and
- Internal boundary conditions (including internal air temperature, internal humidity and surface resistances for heat and water vapour transfer).

Separate calculation requirements are set out for issues such as:

- designing the building envelope to prevent adverse effects such as mould growth on surfaces, corrosion and other moisture damage;
- limiting surface condensation on windows and their frames;
- determining the annual moisture balance and the maximum amount of accumulated moisture due to interstitial condensation (general notes advise that: "The method is an assessment rather than an accurate prediction tool. It is suitable for comparing different constructions and assessing the effects of modifications. It does not provide an accurate prediction of moisture conditions within the structure under service conditions."); and
- drying of building components.

In the calculation of interstitial condensation, the Standard notes that: "The only effect of air movement considered is the presence of a continuous air cavity, which is well ventilated to the outside as defined in ISO 6946 (Building components and building elements – Thermal resistance and thermal transmittance – Calculation Method). The effect of air movement through the building component is not considered." Where a building element contains such a ventilated layer, the Standard says to "take no account of all material layers between the cavity and outside".

This standard also recognises several sources of error caused by the simplified calculation of interstitial condensation. These include the following:

- The thermal conductivity depends on moisture content, and heat is released/absorbed by condensation/evaporation. This will change the temperature distribution and saturation values and affect the amount of condensation/drying.
- The use of constant material properties is an approximation.
- Capillary suction and liquid moisture transfer occur in many materials and this may change the moisture distribution.
- Air movements within building materials, gaps, joints or air spaces may change the moisture distribution by moisture convection. Rain or melting snow may also affect the moisture conditions.
- The real boundary conditions are not constant over a month.
- Most materials are at least to some extent hygroscopic and can absorb water vapour.
- One-dimensional moisture transfer is assumed.
- The effects of solar and long-wave radiation are neglected except for roofs.

This International Standard is not intended to be used for building elements where there is airflow through or within the element or where rain water is absorbed."

Five informative (i.e. non mandatory) annexes offer advice on determining internal boundary conditions (Annex A), examples of calculating the temperature factor at the internal surface to avoid critical surface humidity (Annex B), examples of calculation of interstitial condensation (Annex C), an example of the calculation of the drying of a wetted layer (Annex D) and the relationships governing moisture transfer and water vapour pressure (Annex E).

Annex C is extensive and provides five examples of calculating interstitial condensation. One case, covering a flat roof with a well-ventilated cavity between the roof cladding and insulation, demonstrates how the thermal properties of the roof and its bounding air films are disregarded for the calculation.

Appendix F References and further reading

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