ABCB

CONDENSATION IN BUILDINGS

INFORMATION HANDBOOK

2013

Important Notice and Disclaimer

This Handbook on Condensation in Buildings is one in a series of Information Handbooks produced by the Australian Buildings Codes Board (ABCB) with the aim of providing construction industry participants with advice and guidance on specific topics. This Handbook is not mandatory or regulatory in nature and is provided for general information only. It should not be taken as advice in relation to any particular circumstances.

Users must exercise their own skill and care with respect to their use of this Handbook and carefully evaluate the accuracy, currency, completeness and relevance of the material within the Handbook for their purposes. Users should obtain appropriate professional advice relevant to their particular circumstances. The ABCB, the participating Governments and the groups which have endorsed or been involved in the development of this Handbook expressly disclaim all liability arising from or connected to the use of, or reliance on, the information in this Handbook other than in accordance with this Important Notice and Disclaimer.

In particular, the use of this Handbook does not–

- guarantee acceptance or accreditation of a design, material or building solution by any entity authorised to do so under any law;
- mean that a design, material or building solution complies with the National Construction Code (NCC); or
- absolve the user from complying with any Local, State, Territory or Australian Government legal requirements.

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Preface

The Inter-Government Agreement (IGA) that governs the ABCB places a strong emphasis on reducing reliance on regulation, including consideration of non-regulatory alternatives such as non-mandatory guidelines, information handbooks and protocols.

This Information Handbook is one of a series produced by the ABCB. The series of Information Handbooks is being developed in response to comments and concerns expressed by government, industry and the community that relate to the built environment. The topics of Information Handbooks expand on areas of existing regulation or relate to topics which have, for a variety of reasons, been deemed inappropriate for regulation. The aim of the Information Handbooks is to provide construction industry participants with non-mandatory advice and guidance on specific topics.

Condensation in buildings has been identified as an issue that requires guidance because the National Construction Code Series (NCC) provisions dealing with damp and weatherproofing, ventilation, bushfire safety and energy efficiency can affect its risks and consequences. These measures appear in the Building Code of Australia (BCA), Volume One and Volume Two of the NCC.

The Condensation in Buildings Information Handbook elaborates on the condensation risks mentioned in limited detail by non-mandatory advice in the Guide for Volume One and Explanatory Information in Volume Two. Such explanatory notes accompanied the initial energy efficiency measures for Housing introduced in January 2003 (through BCA 96 Amendment 12). Similar information appeared in the Guide with the introduction of energy efficiency provisions for commercial buildings in BCA 2006. This non-regulatory approach recognised the complexity of the environmental, building construction and behavioural factors which contribute to condensation risk and its effective management. The advisory approach is maintained in the BCA and was extended with the publication of the first edition of the Condensation in Buildings Handbook in 2011.

Like its predecessor, this second edition of the Handbook addresses the issues in generic terms. Examples of climate analysis, configurations of roof, wall or floor assemblies and the like are provided only to illustrate general principles. It is expected that practitioners will consider the suitability of those principles before adapting or applying them to particular circumstances and purposes.

Acknowledgements

The first edition of the Condensation in Buildings Information Handbook was developed by industry, coordinated by the Australian Institute of Architects (AIA) and issued by the ABCB which acknowledges the technical expertise and valuable contributions to the first edition of:

Jamie Adams	Bluescope Steel
Richard Aynsley	Building Scientist
Robin Fardoulys	Fardoulys Constructions, Chairman, Australian Construction Industry Forum
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Mark Goodchild	Master Builders Association, NSW
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Andy Russell	Proctor Group Australia
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Mark Sonnermann	Cundall Engineers
Phil Wilkinson	Australian Institute of Refrigeration Air Conditioning and Heating

Drafting Note:

During preparation of this second edition of the Handbook, many individuals have generously provided valuable advice, observations and technical information that have greatly assisted the ABCB. They are not mentioned in this draft for public comment so that they can consider its contents without any suggestion of responsibility for any perceived shortcomings.

Acknowledgements will be made in the final document according to the preferences of those involved so far and those who might engage with its further development.

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1 Introduction

Reminder:

This Handbook is not mandatory or regulatory in nature and 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 ii.

The Handbook also needs to be read in conjunction with the building legislation of the relevant 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 Building Control Authority.

1.1 Background

The Condensation in Buildings Information Handbook is a revised second edition of a document prepared by the Australian Institute of Architects (AIA) and published by the ABCB in 2011. The first edition noted that it was “intended to assist architects, designers and builders in the assessment of the risk of condensation and its consequences”. The 2011 Handbook has attracted considerable attention on the ABCB’s web site, suggesting that interest in these matters extends beyond the community of building practitioners who work with the regulatory provisions of the NCC.

The second edition consolidates information from the first into a more extensively illustrated form in the hope of improving the Handbook’s accessibility and usefulness to a wider audience. It also draws on the insights and recommendations of researchers and practitioners, in Australia and overseas, who continue to explore the complexities of a still developing body of knowledge and report informatively on their understanding and experiences.

The state of flux is acknowledged in ASHRAE Standard 160-2009. This standard, which is outlined in Chapter 6, provides a consensus view from the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) on suitable inputs to advance methods of simulating condensation risk. The Foreword notes that “many items in this standard are based on incomplete information and are, therefore, partially based on the best professional judgment of the standard committee at the time of writing. The development of this standard has pointed to many unanswered questions, questions that hopefully will be addressed and answered by research in the near future.”

While work progresses on unanswered questions, the climate is also in flux. Many buildings designed today will serve in an environment where extreme weather events are predicted to be more frequent and climatic patterns may shift to create unfamiliar combinations of precipitation, humidity and seasonal temperatures. 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.

Drafting Note:

The incidence of condensation problems across Australia remains unclear. The ABCB has asked stakeholders about their firsthand knowledge of verified instances and stakeholders have inquired within their own networks. The responses so far do not provide a clear picture of extent or causes. Certainly problems are occurring and for those dealing with them the effects can be acute. Some respondents are aware of numerous problems but they have often been encountered over a working lifetime and are not clearly associated with particular places, building types, forms of construction or building age. Many comments suggest that problems are often caused by occupants' use of the affected buildings.

1.2 Scope

Condensation is one of many ways that buildings can become wet. This Handbook discusses that risk in some detail but also emphasises the overriding goal of keeping buildings dry – by constructing them to start out acceptably dry; by detailing them to resist the entry of weather and groundwater; by managing the movement and concentration of water vapour; and by ensuring that any unavoidable damp or wetness can dry out faster than more can accumulate.

There are obligations here for designers, builders and building occupiers and the Handbook attempts to provide some information for each stage of a building's life. Although the NCC applies mainly to new buildings, the Handbook also offers advice for occupants of existing buildings where condensation has become a real or anticipated concern.

Many of the situations discussed refer to single dwellings or domestic forms of construction. That focus is deliberate because these buildings will be familiar to most readers and there are plentiful real examples to consider when interpreting the commentary. Houses are, in the main, 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 ability of the building enclosure to stay dry are not always recognised for what they are.

Some smaller, non-residential buildings that use domestic forms of construction might also apply the principles outlined in the Handbook, although caution is needed where high indoor moisture levels or a specialised building use could amplify the risks beyond those expected in dwellings. Buildings containing commercial kitchens, cool and cold storage rooms, steam generating processes or moisture sensitive materials are examples of cases which need special consideration.

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. Indoor swimming pools, ice rinks, gymnasia, commercial laundries, food processing plants, specialised manufacturing lines, assembly buildings, museums, galleries and archival storage facilities are among them. The Handbook assumes that, the more specialised or complex the building and its functions are, the more likely it is that its proponents will seek out appropriate and informed advice for the design, construction and operation of the building.

1.3 Other Handbooks by the ABCB

The ABCB has produced a range of Information Handbooks and other educational material which can be downloaded from the ABCB website at www.abcb.gov.au.

Handbooks relating to energy efficiency in buildings, which might assist readers of this Handbook, include:

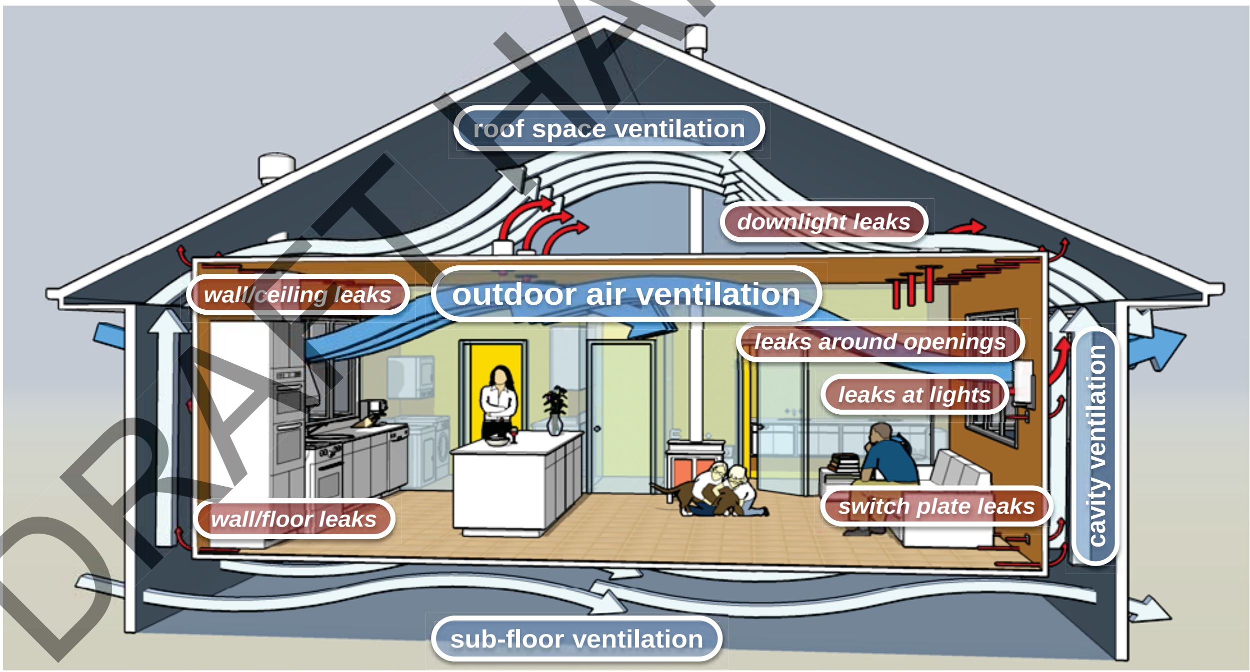
- Energy Efficiency Provisions for BCA 2010 Volume One – Information Handbook;
- Energy Efficiency Provisions for BCA 2010 Volume Two – Information Handbook;
- Energy Efficiency Provisions for Electricians and Plumbers – Information Handbook;
- BCA Section J - Assessment and Verification of an Alternative Solution - Information Handbook;
- Energy Efficiency Glazing Provisions for BCA Volume Two – Information Booklet;
- Using On-site Renewable and Reclaimed Energy Sources – Information Handbook;
- Applying Energy Efficiency Provisions to New Building Work Associated With Existing Class 2 to 9 Buildings – Information Handbook;
- BCA Awareness Resource Kit Module Three – Understanding Energy Efficiency Provisions for Class 1 and 10 Buildings.
- BCA Awareness Resource Kit Module Four – Understanding Energy Efficiency Provisions for Class 2 to 9 Buildings.

2 Overview

Even a dry building contains water. Some of it is confined in pipes, drains and tanks installed to make the building workable. Some is bound up in the microscopic pores of absorbent building materials and contents. Those forms of water are simply out of sight. A crucial and often overlooked part is truly invisible. It is the colourless gas, water vapour, which is always present in the atmosphere, mixing freely with air and going wherever air goes.

As it happens, air travels virtually everywhere in and around the rooms of our buildings (Figure 2.1). Since fresh air is vital for health and amenity, outdoor air is encouraged to 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 by way of holes made for light fittings, light switches, power outlets, pipes and the like. It can also find its way through small gaps under architraves around windows and doors and behind ceiling cornices and skirting boards. In addition, outdoor air is deliberately circulated through roof spaces, wall cavities and sub-floor spaces to help them dry. All of that mobile air carries water vapour with it.

Figure 2.1 – Air and water vapour movement through the building interior and the building fabric

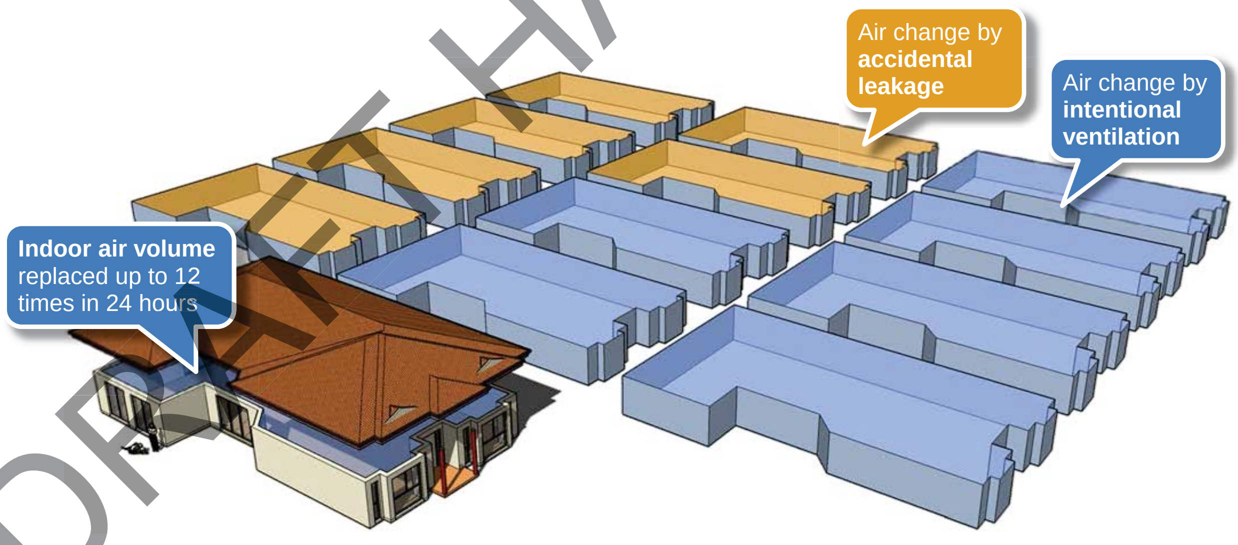


Indoors, people release more water vapour into the air by breathing and transpiring and by daily activities such as cooking, washing, bathing and laundry. In a room where both temperature and humidity are closely controlled, the amount of circulating water vapour might vary from under 0.5% of the moist air mass in a cold climate up to about 1% in a warm humid climate. That is not a lot of water vapour but not much more is needed to cause problems. Chapter 3 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 relative humidity (RH). Relative humidity, which is considered in detail in Chapter 3, is the amount of water vapour present compared to the maximum that could be present at the same temperature. It is always expressed as a percentage. When relative humidity rises towards 50% and beyond, undesirable effects begin, including:

- dust mite proliferation, particularly in bedding, carpets and soft furnishings, producing inhalation allergens (when relative humidity reaches 45-50%);
- mould and fungi growth, including wood rotting fungi (when relative humidity exceeds 70%).

The presence of microbial infestations compromises indoor air quality and can seriously affect asthmatics and others susceptible to allergic reactions. As part of reducing these risks, international guidelines on indoor air quality recommend complete replacement of the air in a dwelling every two to three hours. This means that outside air will flush out the indoor volume between eight and twelve times in every 24 hours. Figure 2.2 represents how much air is involved to achieve the higher ventilation rate. The diagram also highlights that, even in a contemporary “airtight” dwelling, about half of the air (and water vapour with it) will travel through accidental pathways formed by gaps, cracks and holes in the building fabric.

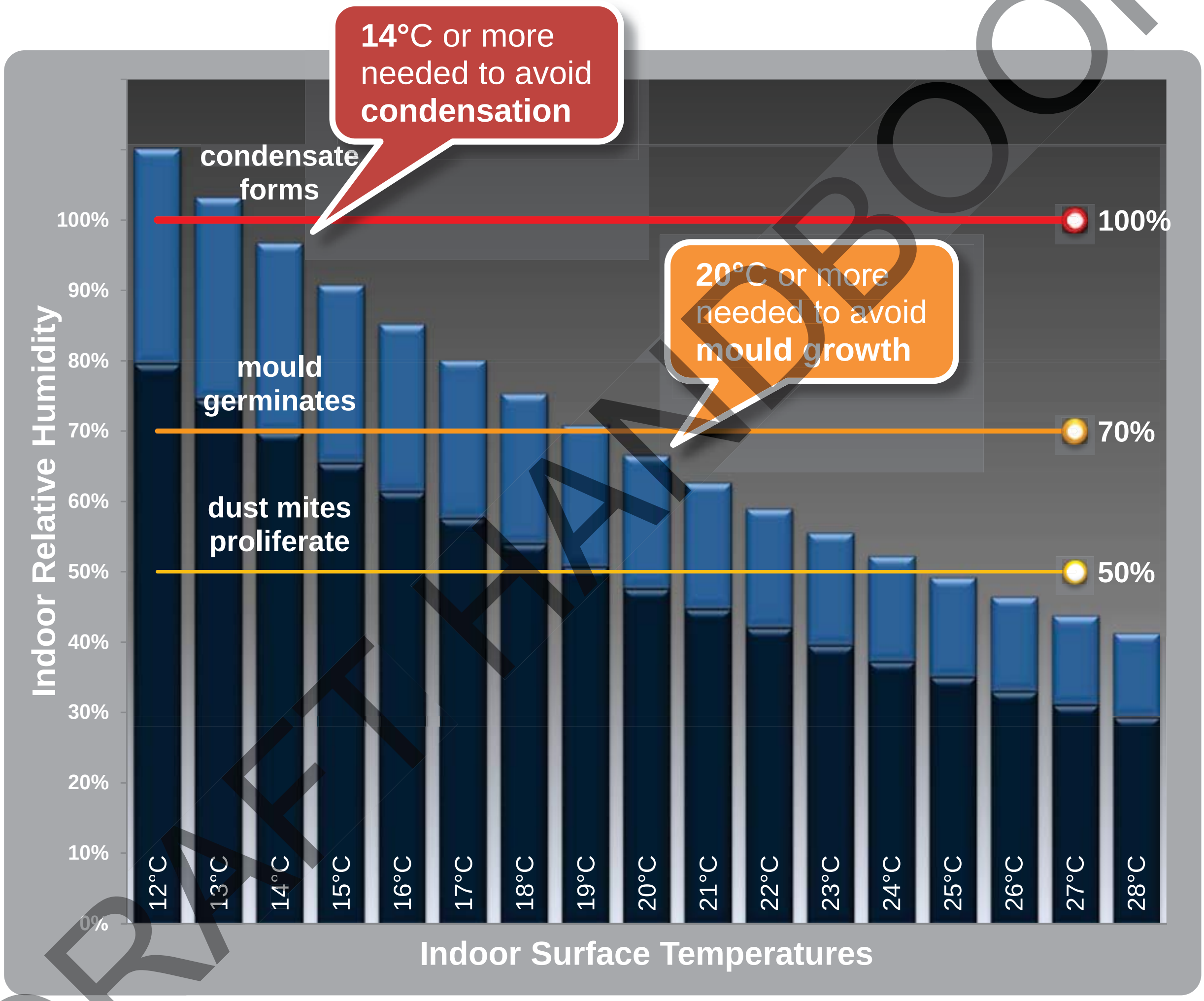
Figure 2.2 – Fresh air ventilation from outdoors for acceptable indoor air quality



Since fresh air supply cannot be reduced below an essential minimum, water vapour brought in with outdoor air can limit attempts to lower water vapour levels indoors (unless an air conditioning system with substantial dehumidifying capacity is involved). Once that limit is reached, relative humidity must be managed by raising the temperature, using active or passive heating. The benefits of controllable heating are illustrated in Figure 2.3.

At each one degree temperature step across the chart, the darker blue lower column shows how much outdoor air for ventilation contributes to the relative humidity indoors. The lighter blue upper column shows the extra effect of water vapour released indoors by the occupants' activities. The relative humidity columns in Figure 2.3 become shorter as temperatures rise although the same total amount of water vapour is involved in each case. Only the relative humidity percentage is changing but that is enough to have the intended effects on risk.

Figure 2.3 – Reducing risks from rising relative humidity by warming indoor surfaces

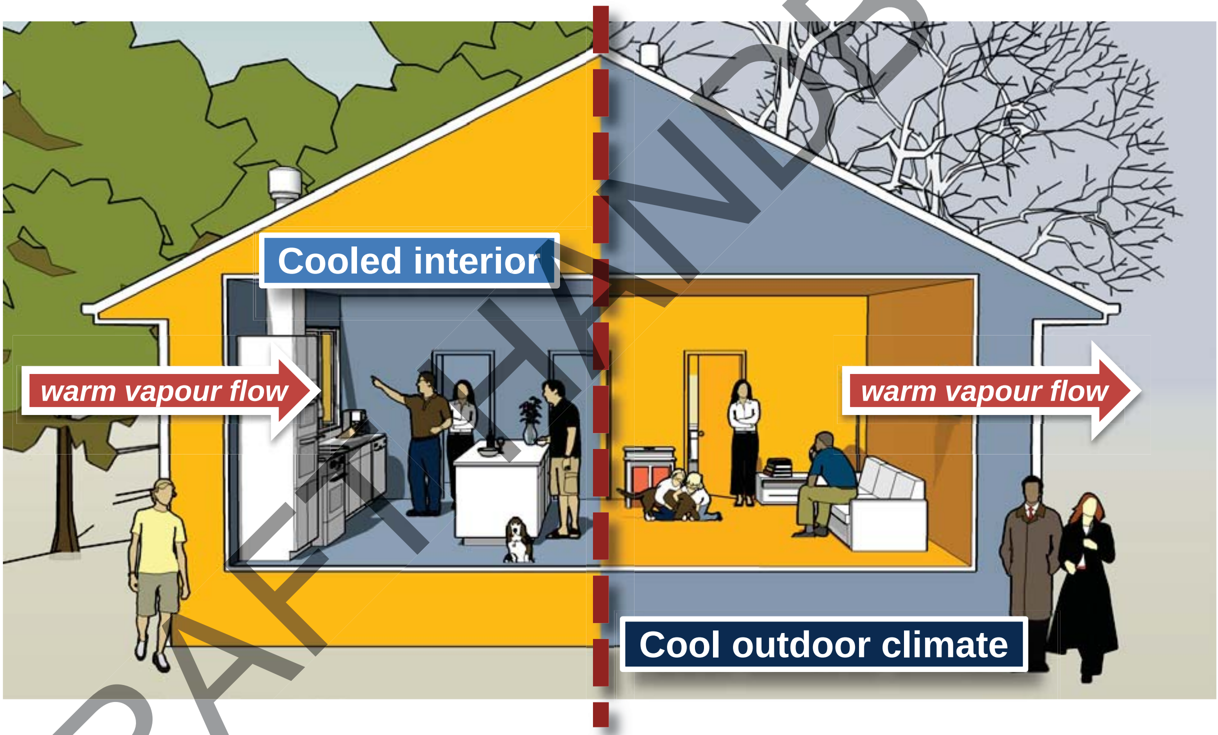


Managing relative humidity and condensation risks indoors begins with the local climate. The climate zones defined for the BCA energy efficiency provisions emphasise typical temperatures over humidity patterns and are not reliable guides when designing and building to avoid condensation. Chapter 4 examines opportunities to apply 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 characteristics of particular places.

Condensation and the risks of higher relative humidity are not confined to colder climates or seasons. They can happen in winter in cold climates when water vapour levels and temperatures are both low but also in the summer wet season of the humid tropics, when there is so much water vapour in the atmosphere that even a small fall in temperature is enough to trigger condensation.

In both situations and in milder climates too, the critical drop in temperature can be caused by the weather or by the use of artificial cooling. Refrigerated air conditioning has opened new frontiers for water vapour to cause problems in situations where it would previously have been unlikely, by cooling building surfaces to temperatures below the usual reach of the natural environment. With growing use of air conditioning in many types of buildings, the effects of cooled interiors and of cool outdoor climates (Figure 2.4) both need to be considered.

Figure 2.4 – Critical temperatures driven by artificial cooling indoors or by the climate outdoors

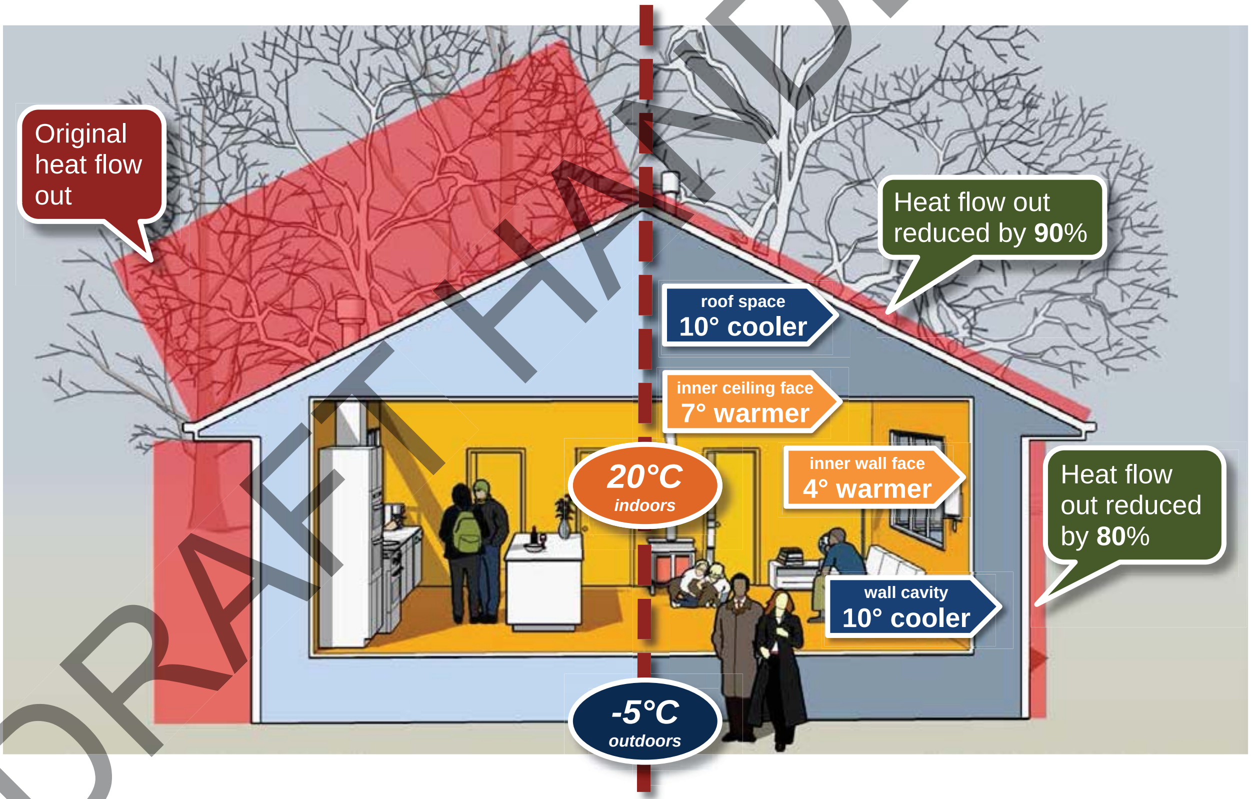


Problems of too much water vapour meeting surfaces cooled too far by air conditioning or by the natural climate can occur in the same geographic location at different times of the year. Longstanding practices of using vapour barriers to limit water vapour migration become problematic when the source of water vapour and the location of critical building surfaces reverse from season to season. Experience from the milder climates of the United States shows that well-intentioned but inappropriate vapour barrier installations can operate instead as critical impediments to drying when water vapour may be flowing either inwards or outwards, according to the season. Chapter 5 takes up the many issues designers and builders need to consider in configuring the building envelope against condensation risk and emphasises the need for a clear understanding of what each layer of a wall, floor or roof assembly should contribute to controlling the movement of water, air, water vapour and heat through the building envelope.

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 2.5 uses Australia's coldest climate conditions 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.

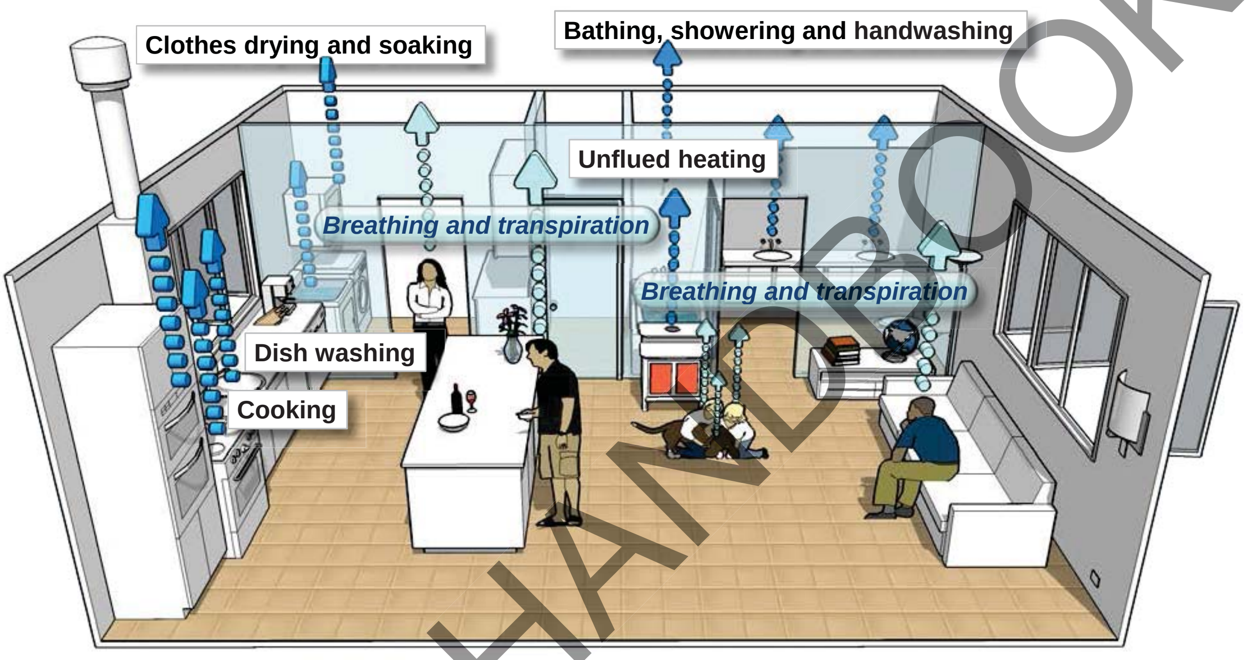
Figure 2.5 – Heat loss and temperature change effects of NCC energy efficiency provisions



The outward heat flows through the roof and wall on the left side of Figure 2.5 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.

Once a building has been designed and constructed with due care to minimise the risks presented by the climate and the intended use of the building, it needs to be operated within the limits anticipated by the designer and builder. Chapter 5 discusses, in the residential context, how to minimise the chances that daily activities in a home or renovations to the building and landscape might compromise the original design intentions. One seemingly common problem is limited understanding of water vapour sources indoors (Figure 2.6) and the benefits of good ventilation to minimise its accumulation.

Figure 2.6 – Water vapour sources in a dwelling which can increase relative humidity



Since the design of new buildings is subject to regulatory requirements laid out in the NCC, Chapter 6 reviews how those requirements might constrain or encourage approaches to managing condensation risks. Possible influences through Performance Requirements and Deemed-to Satisfy Provisions are considered. The discussion extends to Australian and New Zealand standards referenced by the NCC for the design and detailing of the building fabric.

Chapter 6 also outlines international standards dealing with risk assessment methods developed (and still developing) in the United States and Europe, noting their current limitations.

2.1 Overview – Summary:

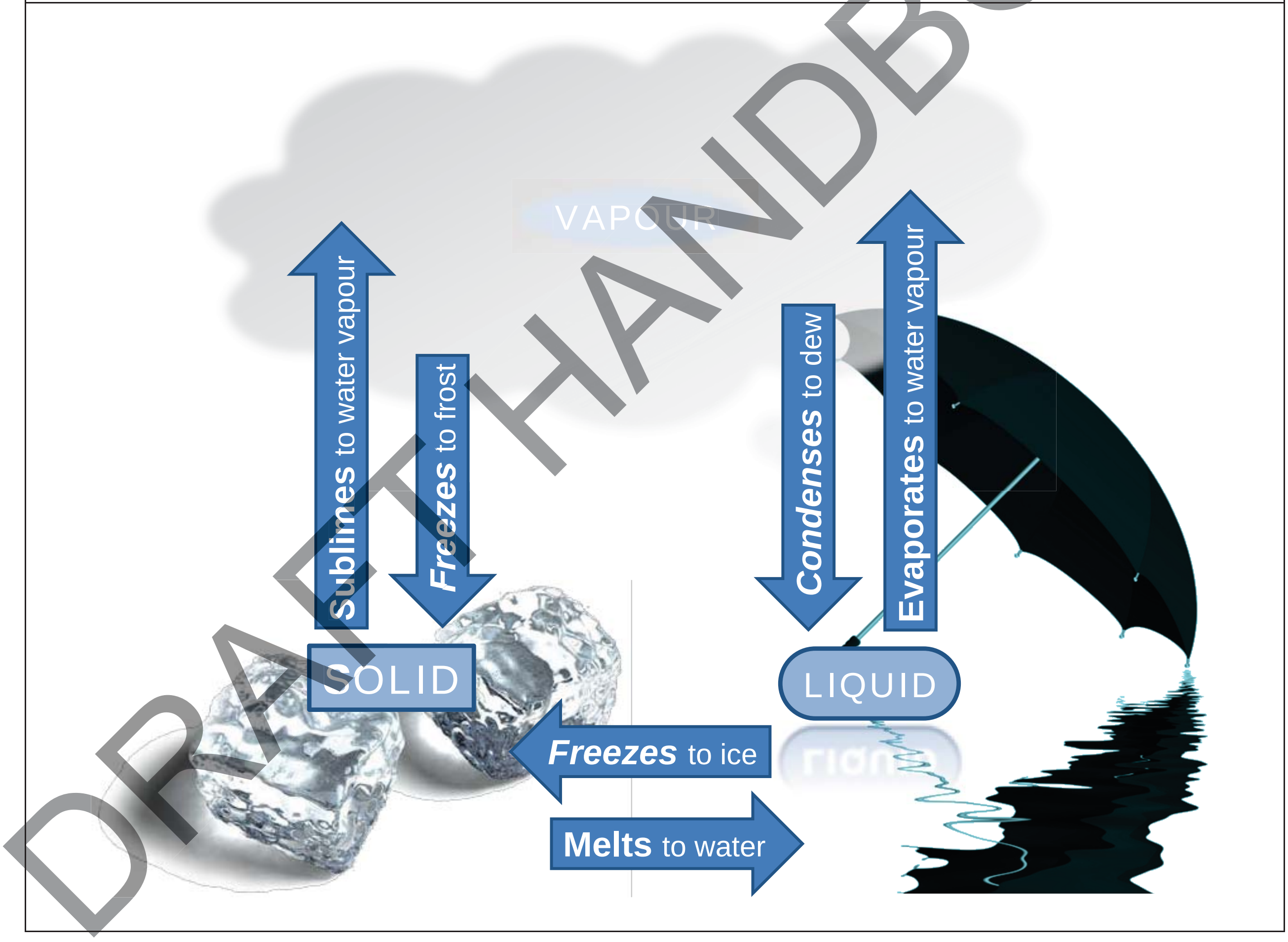
- Water vapour laden air circulates freely through virtually all parts of buildings and even a low concentration of water vapour can be too much when building surfaces are too cool.
- High relative humidity indoors and in the building fabric can cause health risks and material damage before any condensation actually occurs.
- Risks begin with the local climate but can be fundamentally altered between seasons when artificial cooling is used.
- Effective designs for building envelopes must control the movement of water, air, water vapour and heat into and through the building fabric.
- When a building is in use, limiting the accumulation of water vapour requires attention at its sources and to effective ventilation.
- The design and detailing of new buildings to manage the unavoidable presence of water vapour must take account of regulatory provisions and may benefit from risk analysis methods and supporting information set out in international standards.

3 Water Vapour

3.1 Water

Among commonplace substances, water has the unique ability to be a solid, a liquid or a gas at ordinary temperatures. Figure 3.1 shows that 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.

Figure 3.1 – Possible changes between forms of water at ordinary temperatures



Mist on a bathroom mirror is inconvenient but a slippery film of condensate on a tiled floor can be dangerous. Similar 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 because water vapour has the mobility of a gas and the versatility to revert to a liquid in parts of the building enclosure that water would not be expected to reach.

3.2 Water Vapour

Water vapour is invisible. Clouds and jet trails, fogs and mists are not water vapour but are accumulations up of fine, floating water droplets or ice crystals. “Steam” noticed rising from boiling water, cooking pots, a shower head or a bath is the same (without the ice). 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.

Water vapour is nothing more than a swarm of single molecules that have broken free of the surface of water. They need heat to energise their escape but they do not need air to “hold” them or to absorb them. They simply mingle with the molecules of the many gases in air and travel with them in the moist air mass that forms the atmosphere.

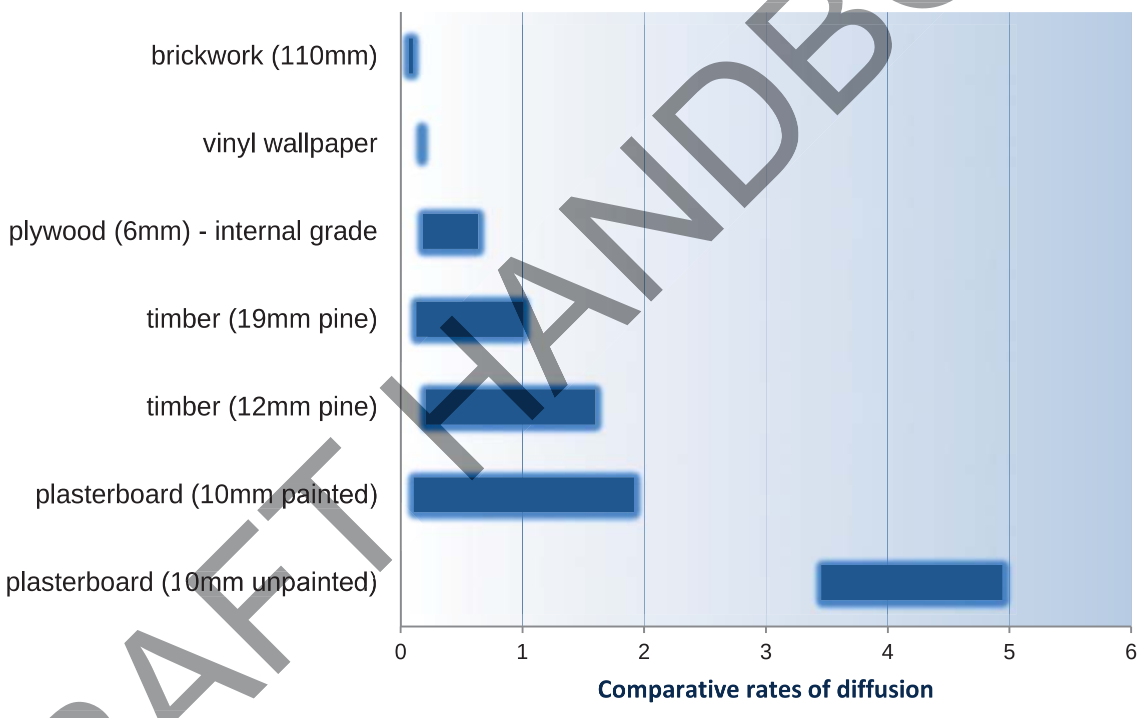
There is always some water vapour in the atmosphere, even in the world’s driest places. The amount varies from just a trace in Antarctica (the driest continent) to as much as 3% by mass in the tropics. In Australia, the water vapour content of the atmosphere can fall lower than 0.25% in alpine areas during winter and reach nearly 2% in the tropical north during the summer “wet”. The relatively small amount of water vapour, even in the wettest places, is not due to any shortage of water but is limited by prevailing temperatures. The limits that temperature sets on water vapour formation and concentration are discussed in Section 3.4.

Perhaps surprisingly, adding water vapour to air makes the increasingly moist air less dense and more buoyant because water vapour molecules are lighter than the nitrogen and oxygen molecules that dominate air. The small size of water vapour molecules also allows them to travel where water and even air cannot.

3.3 Water Vapour Diffusion

Because individual water vapour molecules are much smaller than the clusters of 25 to 75 molecules that make up 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 3.2 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 3.2 – Diffusion of water vapour through some permeable building materials



The driving force for diffusion is a difference in vapour pressure across a material or between spaces. More exactly, it is a difference in “partial vapour pressure”. Each gas in a mixture of gases (such as air and water vapour) acts independently as though it is the only gas present and exerts a vapour pressure which depends on its temperature. The total pressure of the mix is the sum of all of the partial pressures exerted by the individual gases. Atmospheric pressure, for example, is the sum of the partial vapour pressures separately contributed by nitrogen, oxygen, water vapour, argon, carbon dioxide and so on.

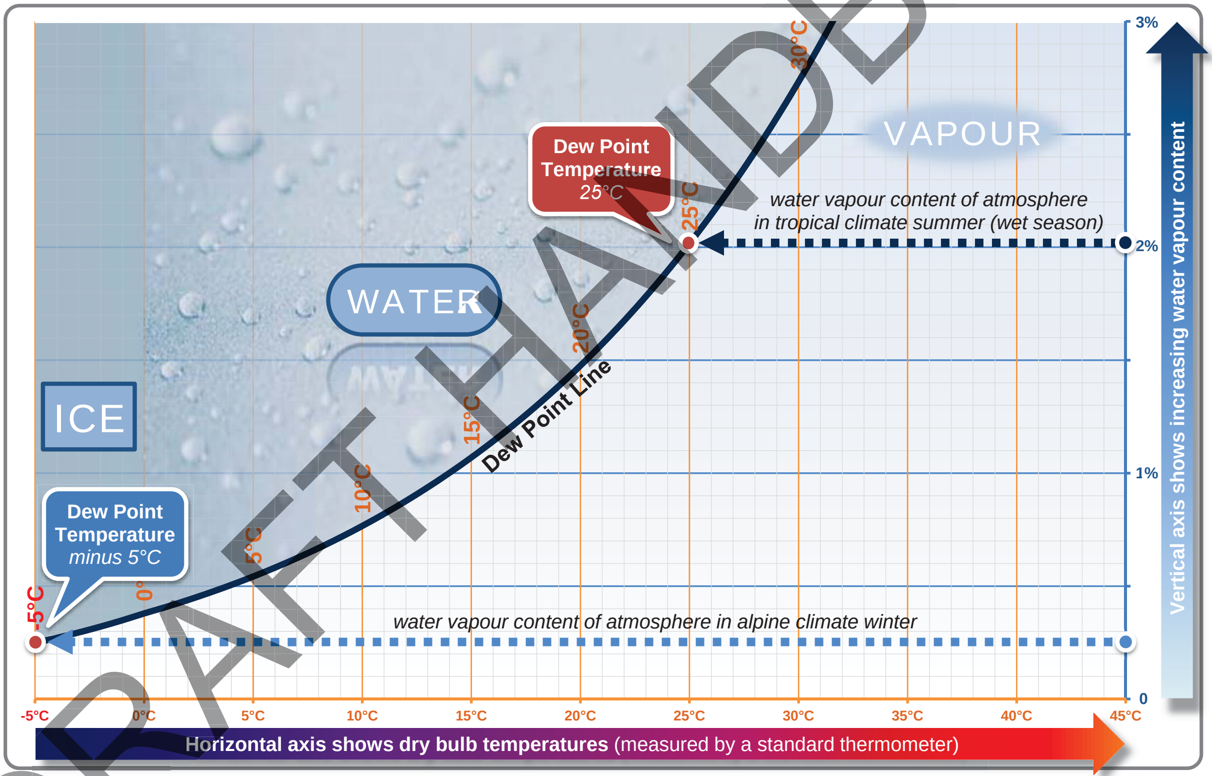
When it comes to diffusion, water vapour responds to differences in its own partial vapour pressure between one place and another, regardless of the overall atmospheric pressure. In practice, diffusion will rarely be the dominant way the water vapour travels within the building fabric. Most water vapour will move with air through accidental or intentional gaps and holes.

3.4 Saturation or Dew Point

Temperature determines how many molecules 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 better understood when mapped on a psychrometric chart. (Psychrometry measures changes in the conditions of water vapour at various concentrations and temperatures.) The pictorial chart in Figure 3.3 is simplified for introductory purposes.

Figure 3.3 – Elements of the psychrometric chart



In this version, the chart covers temperatures from minus 5°C to 45°C, on the horizontal axis, and water vapour levels ranging from (a theoretical) zero up to about 3% of the atmosphere, on the right hand vertical axis. 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 means just what the name suggests. It is the temperature where condensation begins as a certain concentration of water vapour cools. 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).

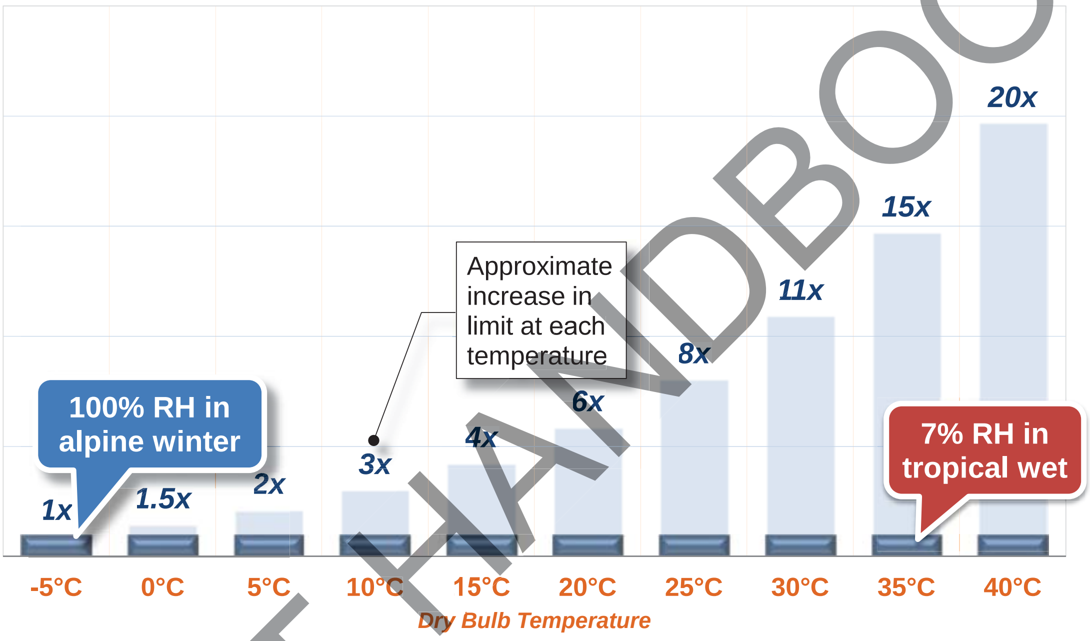
Two blue dotted lines across the chart illustrate how atmospheric water vapour levels vary across Australian climates. The lower line shows water vapour levels typical of the alpine winter; the upper line is for the tropical wet season. The intersection of each line with the dew point curve marks the dew point temperature in each case. There is so little vapour present in the cold alpine climate that the temperature must fall to nearly minus 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. A comparison of climate characteristics in Chapter 4 demonstrates that both locations can deliver temperatures low enough to reach dew point.

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 more familiar relative humidity (RH) is always 100%.

3.5 Relative Humidity

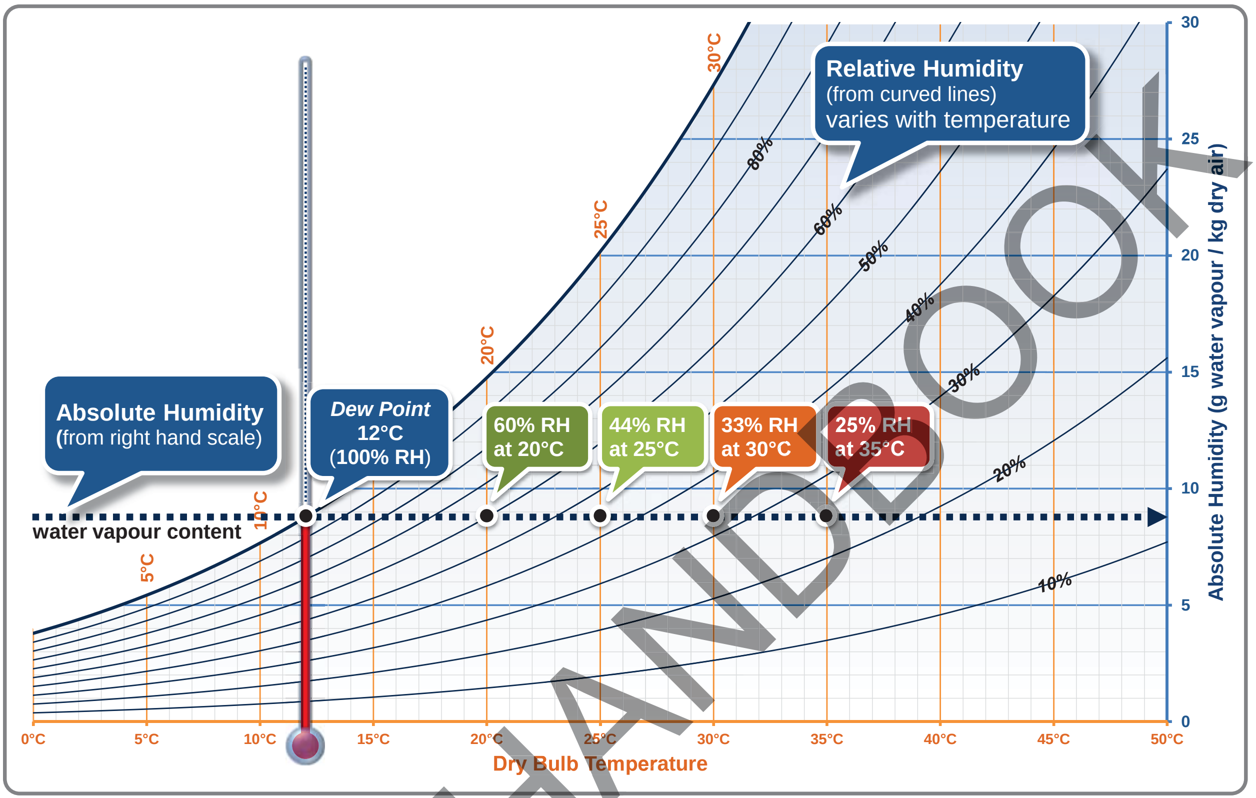
Relative humidity measures how much water vapour is present compared to the most that the prevailing temperature could potentially support. Figure 3.4 compares limits as temperatures rise with a small fixed amount of water vapour. The fixed amount represents 100% relative humidity in an alpine temperature but smaller and smaller percentages at warmer temperatures.

Figure 3.4 – Water vapour limits rising with temperature and relative humidity falling



Changes in relative humidity as temperatures rise or fall are indicated on a standard psychrometric chart by curved lines of the sort shown in Figure 3.5. This version of the chart uses the same temperature range (0°C to 50°C) along the horizontal axis as the standard chart and the right hand vertical axis measures the water vapour content of the atmosphere, or its absolute humidity (AH), in grams of water vapour per kilogram of dry air.

Figure 3.5 – Absolute and relative humidity on the psychrometric chart

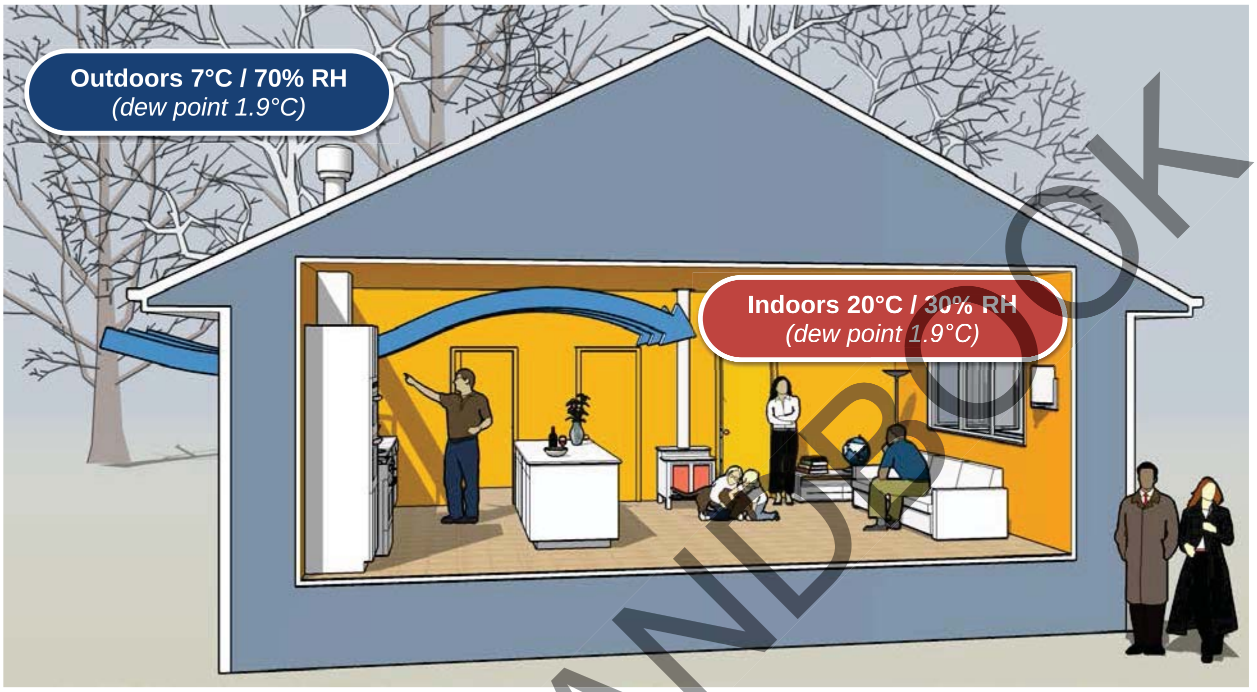


To illustrate the difference between absolute and relative humidity, a dotted line runs horizontally across the chart from the 12°C point on the dew point curve. Where the line meets the right hand axis marks the absolute humidity for water vapour with that dew point. Points marked along the same dotted 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 relative humidity has fallen from 100% (its dew point) to 60%. At 35°C, the relative humidity has declined to 25% although the amount of water vapour in the atmosphere (its absolute humidity) has not changed at all.

Unlike a dew point temperature, a relative humidity percentage does not identify how much water vapour is present unless a temperature is also specified. 100% relative humidity, 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 relative humidity at low temperatures even if absolute humidity is low. Similarly, high relative humidity can fall away as temperature rises.

Moving from the psychrometric chart to a building-related example, Figure 3.6 shows relative humidity in outdoor air decreasing in a heated interior. Water vapour introduced with fresh air from outdoors is heated from 7°C to 20°C, lowering its relative humidity from 70% outdoors to 30% indoors. The absolute humidity of the water vapour, indicated by its dew point of 1.9°C, remains the same indoors and out.

Figure 3.6 – Warmer indoor temperature lowering relative humidity of fresh air from outdoors

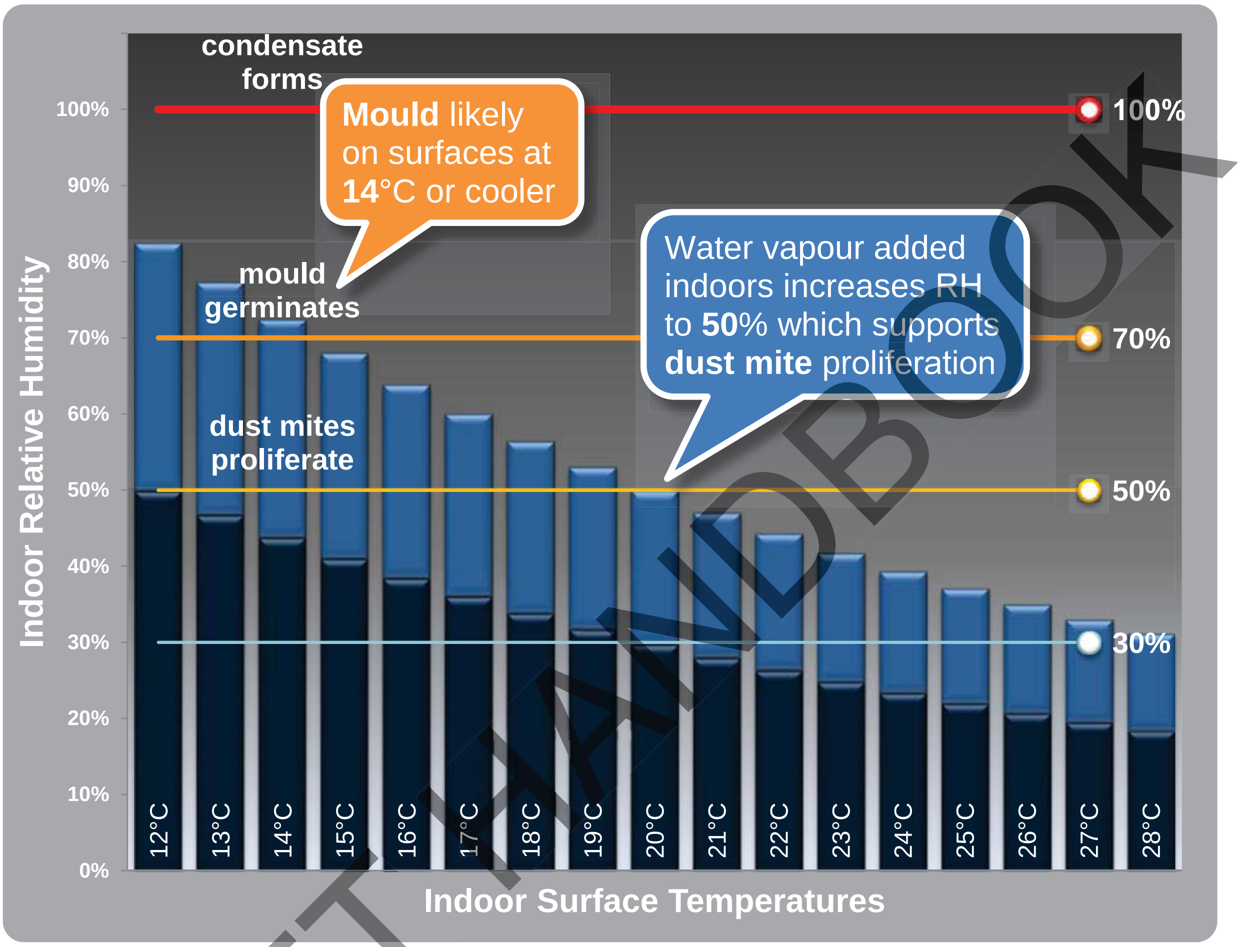


In reality, outdoor air is not the only source of water vapour that will influence the relative humidity indoors. All occupied buildings have their own internal sources of water vapour due, in part, to the breathing of the occupants. An adult breathes out about 200 grams of water vapour each hour while awake (and engaged in sedentary activities) and about 20 when sleeping. Evaporation from the skin will provide some more. In a residence, daily hygiene and housekeeping involve many activities that release water vapour.

The amount of water vapour that might be added to the interior of a dwelling depends on the number of people (and pets) living there, how active they are, how much cooking, dishwashing, laundry, showering and bathing they do, what they choose to store or keep around them and what heating or cooling arrangements they use. How much of the added water vapour accumulates inside the building will depend also on the rate of ventilation and the use of any extraction systems to capture water vapour near its source and discharge it directly outside.

A family of four could easily generate between 7 and 22 kilograms of water vapour per day, even allowing for absences at work and school. Which part of the range applies would depend on how much of the water vapour is diverted outdoors from sources such as bathrooms, laundry, cooking and gas heating. Figure 3.7 shows how extra water vapour, near the higher end of the range, could affect the 30% indoor relative humidity indicated in Figure 3.6. Even for a well-ventilated house, the relative humidity 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, relative humidity rises further and mould germination becomes possible at 14°C.

Figure 3.7 – Warmer indoor temperature lowering relative humidity of fresh air from outdoors



The psychrometric chart in Figure 3.5 illustrates relative humidity falling as temperatures increase but the risks for buildings stem from the rising relative humidity 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 3.7, unwelcome effects can emerge before relative humidity reaches 100% and the dew point when condensation begins.

3.6 Problems with Relative Humidity

Relative humidity can be too low as well as too high. Low relative humidity 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 relative humidity is usually not much more than 10%. Simple measures of human comfort often suggest 30% relative humidity as a lower limit and 60% as an upper limit (without mentioning a matching temperature range). Higher relative humidity can interfere with natural skin cooling by evaporation of perspiration and lead to a familiar “sticky” feeling. Inside the 30-60% band suggested for human comfort, problems can arise because other creatures also feel at home.

House Dust Mites

House dust mites are habitual companions in many human environments. They dine mainly on human skin scale and, in return, release allergens in their faeces which can affect susceptible individuals. Dust mites absorb the water they need directly from the air and are viable when relative humidity reaches 45-50%. They need exposure to this level for only an hour each day to become fully hydrated. At higher levels, they feed and multiply more rapidly.

Controlling house dust mite population is not simply a matter of keeping relative humidity below 50% because they favour life in carpets, curtains and bedding which are difficult to keep dry enough. Carpets on concrete slabs are particularly prone to dust mite infestation because the surface temperature is likely to be lower than other room surfaces unless the slab is insulated.

Figure 3.8 – The house dust mite (which is viable when it finds local relative humidity above 50%)
(Source: BRANZ 2012)

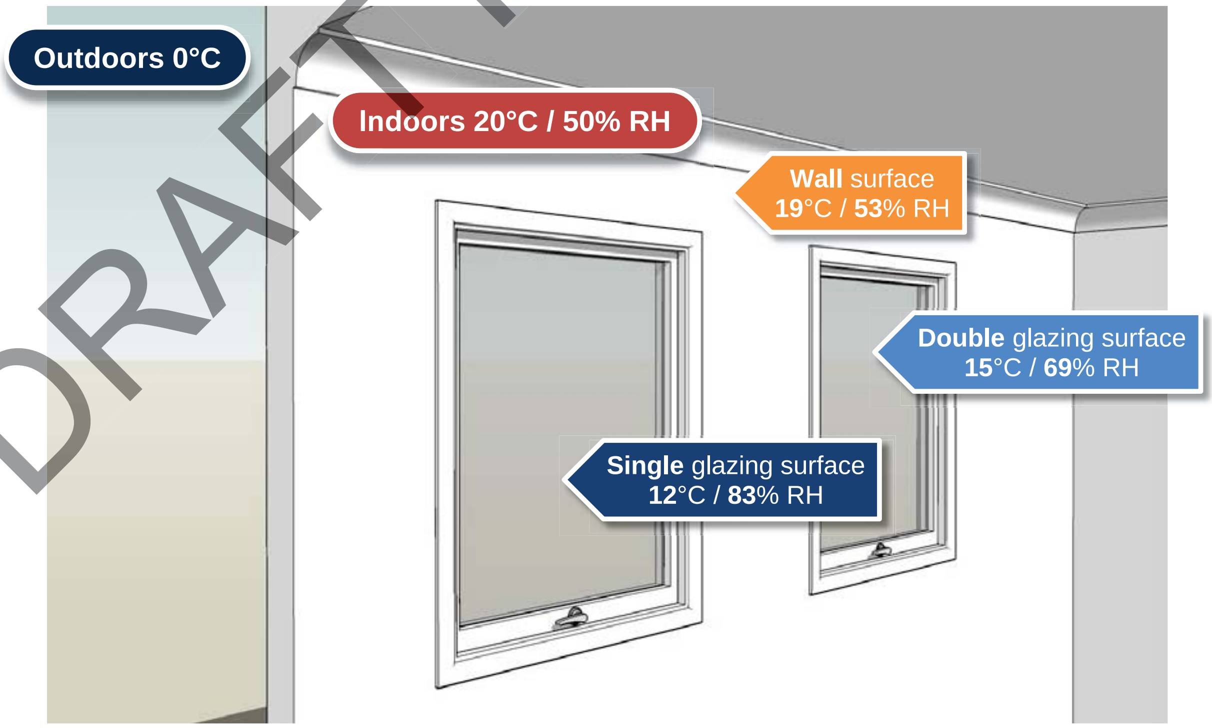
Mould, Mildew and Fungus

Above 60% relative humidity, problems emerge which can more easily be seen. Moulds and fungus, for example, can develop on surfaces in a building or its contents when spores are present with a sufficient nutrient supply, temperatures stay between 4°C and 38°C and relative humidity rises above 70% at the surface. Left to develop, these organisms can produce toxins and irritants with suspected effects on respiratory health. The first two conditions for growth are easily met because spores are always present in the air and most building materials or furnishings and contents can supply the nutrients. Keeping building occupants comfortable will also ensure that temperatures are amenable for mould, mildew and fungus.

These realities require that mould growth be kept in check by controlling relative humidity adjacent to building surfaces. This means minimising water vapour levels and keeping temperatures up at the surfaces since relative humidity depends on both temperature and water vapour concentration. Although air temperature in a room might be at the preferred level, some parts of the walls, floor and ceiling or furnishings can be significantly cooler. This can apply over the whole area or be localised, depending on construction, local shielding from air movement by furniture and fixtures and on heating and cooling arrangements.

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 and 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. Surfaces inside cupboards and behind or under furniture that limit the circulation of warmed air or intercept radiant heat are also at risk. Windows, however, may show problems first because they often have the coldest surfaces in a room and respond quickly to falling temperature (Figure 3.9).

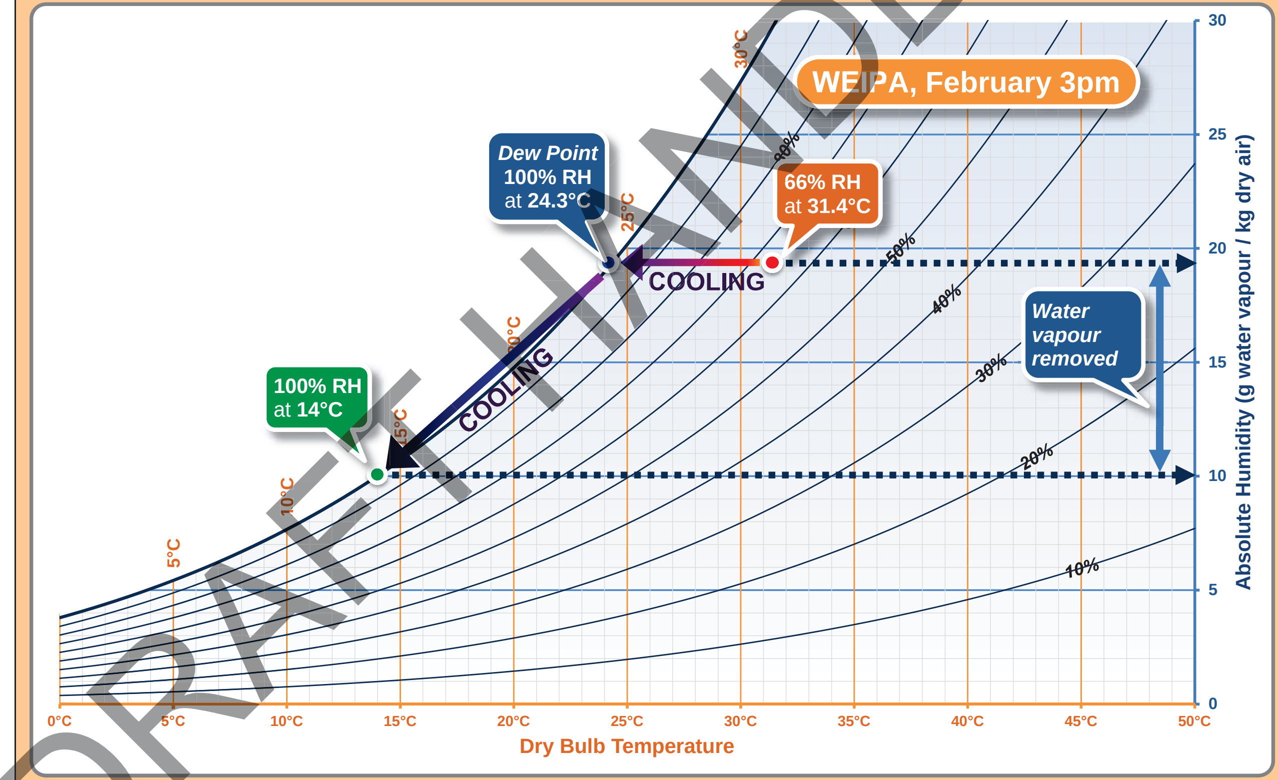
Figure 3.9 – Surface temperatures of glazing in interior heated to 20°C (outdoors 5°C)



In warmer climates or seasons, when air conditioning is used, cooling warm outdoor air will increase the relative humidity. Where water vapour levels in the atmosphere are high, relative humidity indoors is likely to exceed the 70% needed for mould growth. Excessive cooling, without effective dehumidification, can create 100% relative humidity (and dew point) at the cooler surfaces.

Example: Increasing relative humidity by cooling

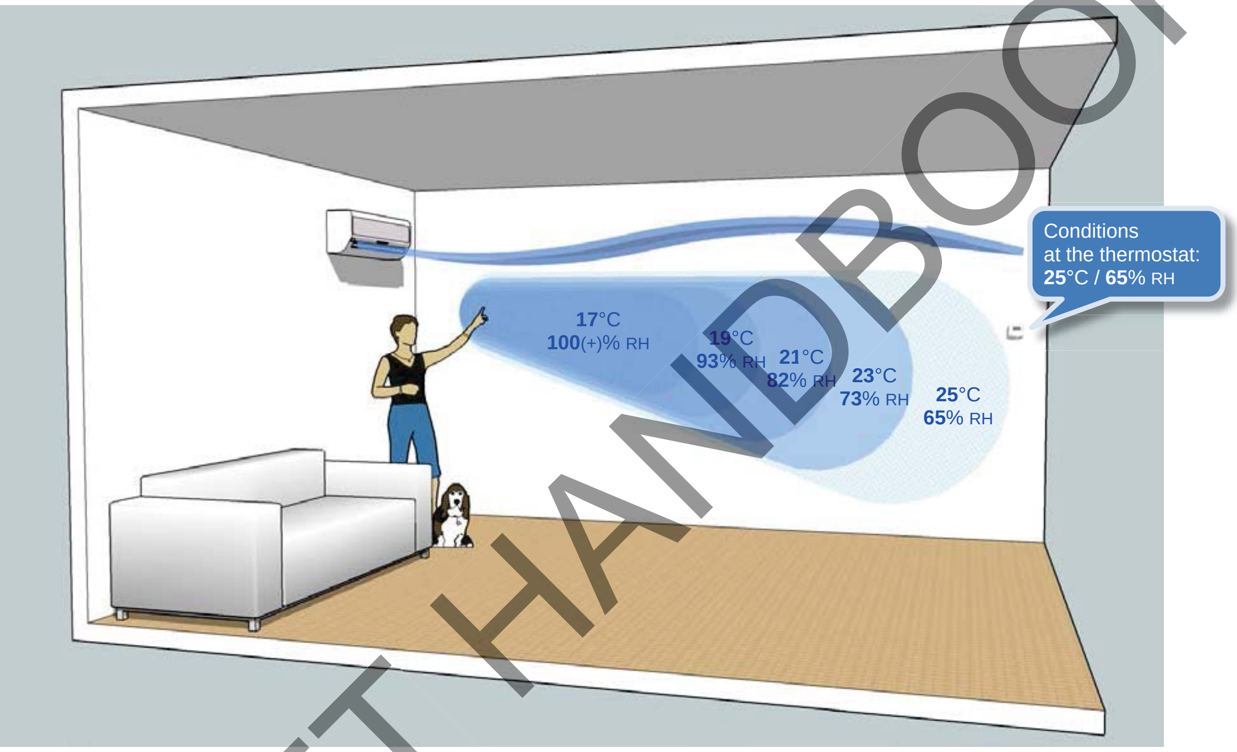
In Weipa, during February, the outdoor air has a mean maximum temperature of 31.4°C and a 3pm dew point of 24.3°C, indicating a relative humidity of 66%. If this outside air is cooled to 25°C (with the temperature moving leftwards across the psychrometric chart below), relative humidity rises to 96%. Cooled slightly further, it will reach its dew point and water vapour will begin to condense.



Cooling to any lower temperature will unavoidably remove water vapour by condensation and lower the absolute humidity. Energy will be used to reduce the temperature of the air and to remove the heat (latent heat of condensation) released by the condensing water vapour. The relative humidity at the lower temperature will always be 100% but the absolute humidity (on the right hand scale) will have fallen significantly.

Air will often be chilled below the target indoor temperature, to compensate for mixing with warmer air in the room. If poor diffuser design or placement allows the chilled air to blow against a wall or floor surface (Figure 3.10), it can create cold patches on the surface where the relative humidity will be higher than the general level in the room. The cooling effect can extend through the lining into surfaces concealed inside the building fabric. Water vapour from outdoors leaking through the envelope construction can then trigger mould growth where it cannot easily be detected, but can still harm indoor air quality.

Figure 3.10 – Localised variation in surface temperatures with artificial cooling



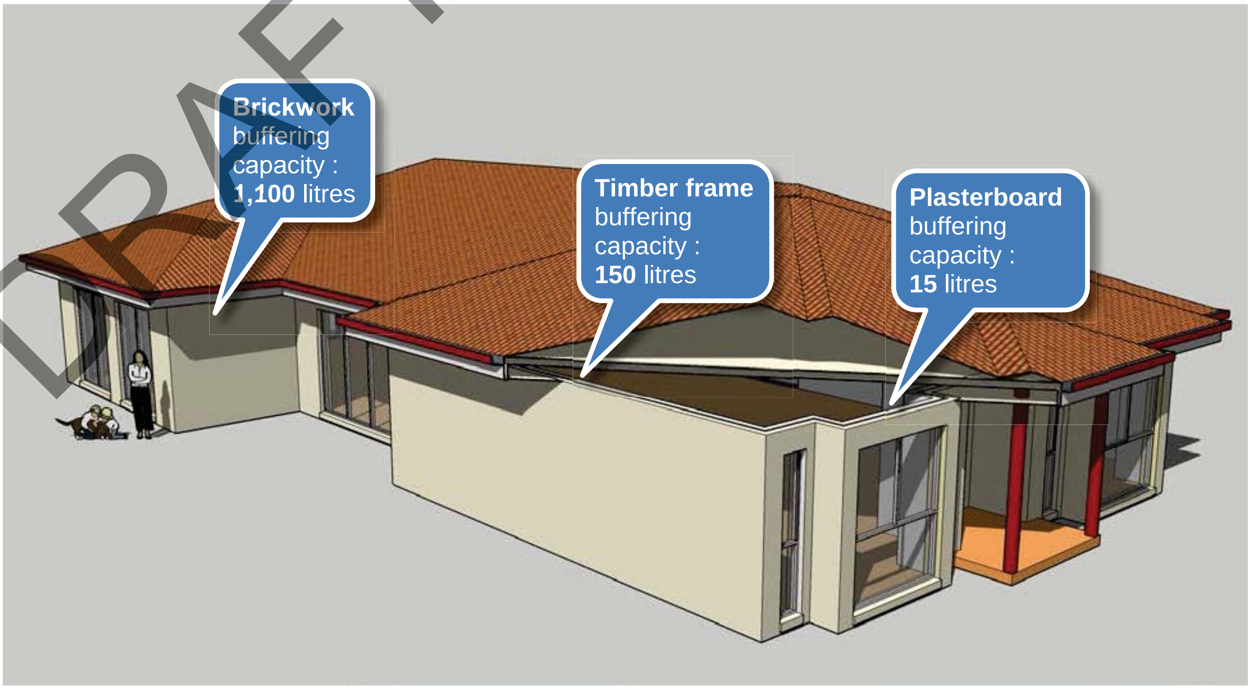
3.7 Material Responses to Relative Humidity

There are many building materials which are 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% relative humidity 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 relative humidity rather than to absolute humidity. They take in more water vapour when relative humidity is high and release it when relative humidity falls. Since relative humidity rises as temperatures go down, cooler temperatures will increase water vapour capture and storage in hygroscopic materials. This response to relative humidity can provide a useful hygric buffer or safety margin when water vapour levels are rising or temperature is falling. Figure 3.11 shows the approximate temporary storage capacity of the three main components of the external walls of a modest brick veneer dwelling.

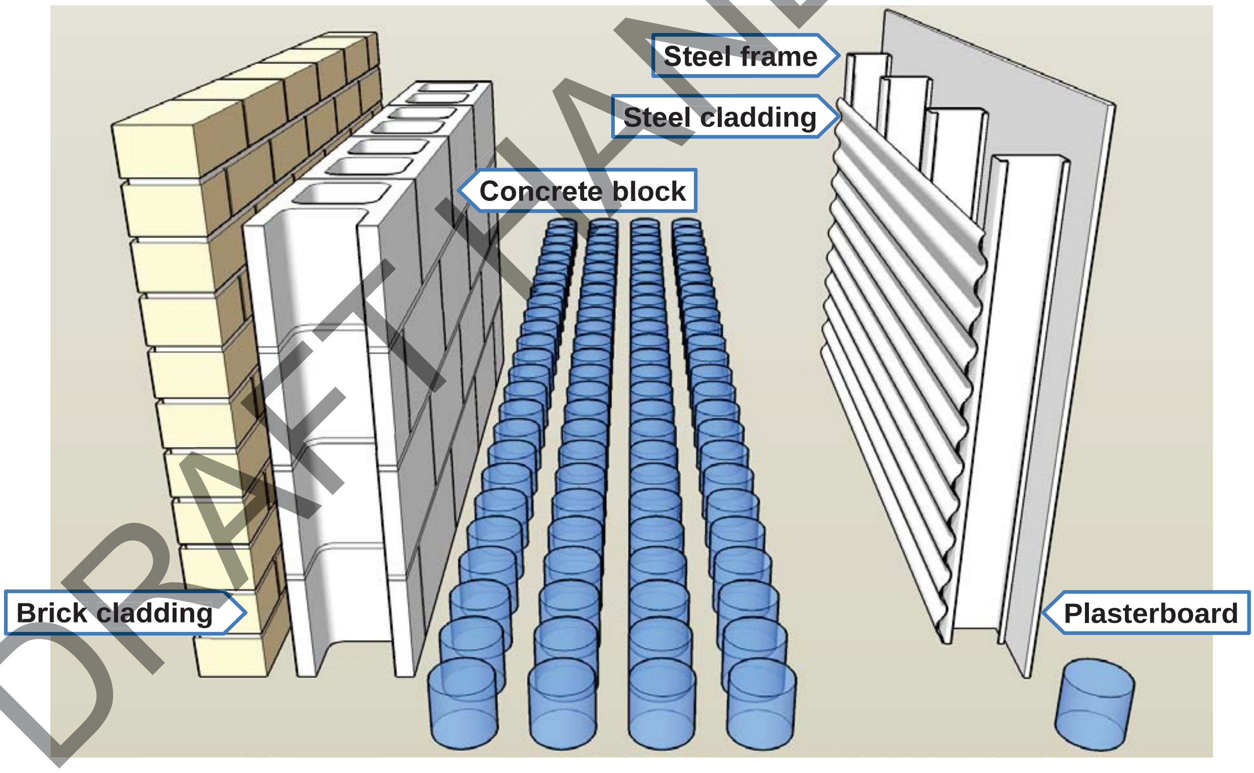
Figure 3.11 – Storage capacity of materials in the external walls of a 185 m² brick veneer house



Safe storage capacity in the building fabric can immobilise water vapour when relative humidity is rising and release it when drying conditions prevail. The interior of the house in Figure 3.11 would have about 4 litres or kilograms of water vapour in the air when the indoor temperature is 20°C and relative humidity is 50%. Adding one more kilogram would take relative humidity up to the 70% threshold for mould growth. Four more would bring relative humidity to 100% or dew point. The interior plasterboard lining, in first contact with this airborne water vapour, can take up some of it by adsorption and help to stabilise relative humidity at less problematic levels.

Taking account of the timber frame behind the plasterboard 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. The comparative storage and buffering capacities of lightweight and high mass walls are illustrated in Figure 3.12. This sort of variation is highlighted in Chapters 4 and 5 as an important consideration when selecting envelope construction for buildings in locations with greater risk of condensation or with higher indoor water vapour loads.

Figure 3.12 – Indicative range of moisture storage capacity in masonry and light framed walls



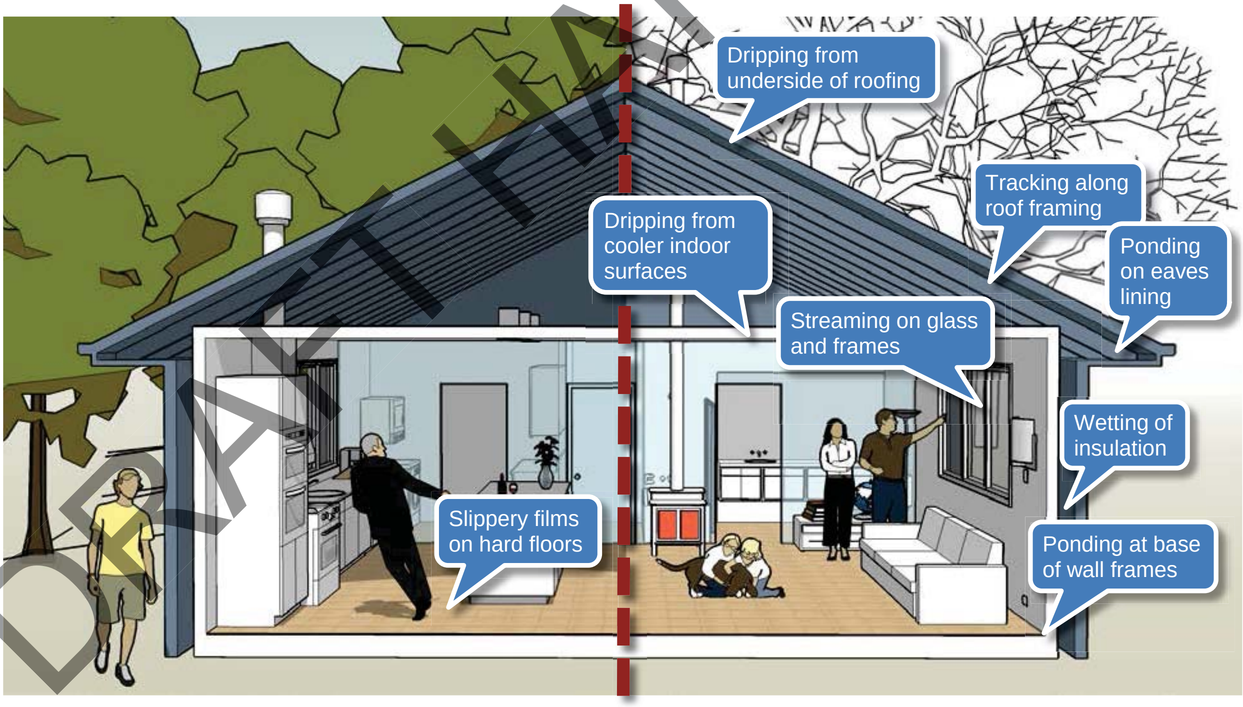
Relying on the hygric capacity of the building envelope construction is not a panacea for avoiding problems with water vapour. Some of the capacity will be needed to deal with periodic wetting by rain, surface water or rising groundwater, and some for construction moisture in the building fabric itself (such as water in concrete slabs or steam cured concrete blocks). Chapter 5 considers the demands on the building envelope and the measures needed to ensure that water (as liquid or vapour) is excluded as far as possible and does not accumulate faster than it can dry.

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. In the 1990s, installation of polyethylene vapour barriers suited to very cold climates became widespread in milder American and European locations to deal with lower wintertime condensation risks. The unexpected consequence was that these barriers, located on the interior face of wall insulation behind the lining became the site of condensation in summer from moisture driven out of brick veneer and similar claddings (Lstiburek 2001). Since such practices were not applied in Australia, the issue is little known here but may serve as a cautionary example of failing to recognise the year round effects of strategies to manage water vapour risks.

3.8 Consequences of Condensation

Once relative humidity of water vapour at a surface has reached 100% and dew point, it will revert to liquid water or frost. Figure 3.13 illustrates a number of risks that may follow.

Figure 3.13 – 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 and a search for the cause begins in the wrong places. The “leak” might not be due to a weather event but to periodic condensation which outpaces any intermittent drying. Condensate forming as a persistent surface film under a cold roof, for example, can develop over time into droplets and streams which run or drip onto other materials where the first evidence of a problem is seen. One strong indication that a phantom leak could be at work is when water emerges in the absence of significant rainfall.

Problems can occur out of sight inside the building fabric. Some building materials are manufactured using chemical preservatives which remain comparatively inert so long as they are dry. In coastal environments, airborne sea salt can deposit on materials before they are enclosed. If liquid condensate later mobilises these chemicals they can damage adjoining materials and corrode metallic fixings and fasteners such as nail plates and brick ties. Condensate forming on electrical wiring or fittings can cause short circuiting and possible shock hazards where conductive materials, including sodden fibrous insulation, are present.

Inside rooms, condensate will usually form first on windows (See Figure 3.9) where its presence can serve as an early warning of high relative humidity. Less easily noticed and more hazardous is the formation of condensate films on cold floor surfaces (left side of Figure 3.13). The surface temperature of concrete floor slabs in direct contact with the ground depends significantly on the underlying soil temperature. The soil temperature tends to follow the seasonal average air temperature but lags about 30 days behind it. This allows the slab surface temperature, particularly on tiled floors, to remain considerably cooler than the indoor air on warming days following a colder period. If the weather is also humid, a slippery film of condensate can form, possibly unnoticed, on a non-absorbent floor surface.

In general, the impact of accumulating condensate from water vapour will be no less damaging and no more welcome than spills and leaks of liquid water.

3.9 Water Vapour – Summary:

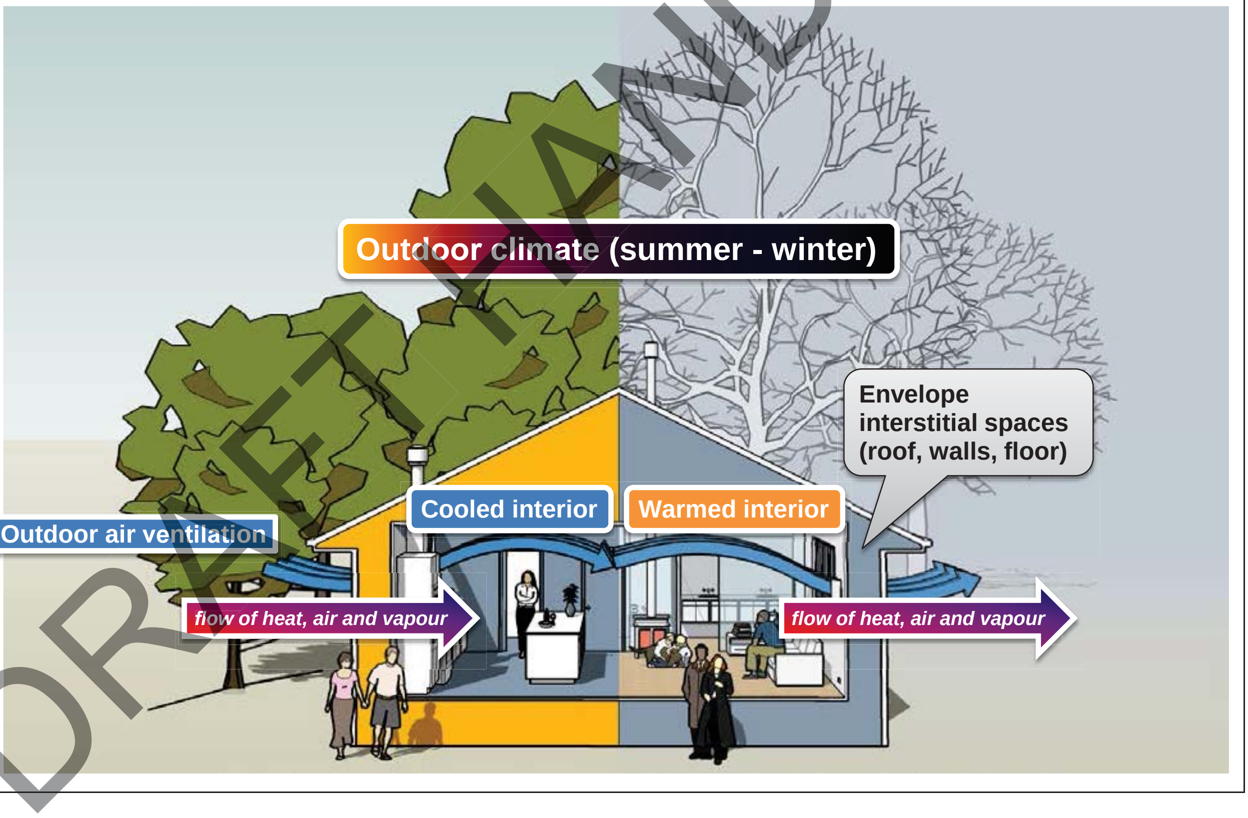
- Water vapour can form at everyday temperatures, travel freely in air and condense in parts of a building where liquid water or frost might be dangerous or damaging (Sections 3.1-3.2).
- Water vapour can diffuse through some materials which would hold back liquid water and air, driven by differences in partial vapour pressure of water vapour from one side of the material to the other. Diffusion occurs from the higher to the lower partial vapour pressure (Section 3.3).
- There is a limit to how much water vapour can form by evaporation at any given temperature (its saturation limit). Similarly, there is a limit to how far a smaller amount of water vapour can cool before it begins to condense. The lower temperature limit is the dew point temperature for that concentration of water vapour (Section 3.4).
- A psychrometric chart allows easy identification of saturation limits and dew point temperatures. Although dew points are expressed as temperatures, they also indicate the water vapour content of the atmosphere (or absolute humidity) at that temperature (Section 3.4).
- A relative humidity percentage simply indicates how close water vapour in the atmosphere is to its saturation limit. It does not identify how much water vapour is actually present unless a temperature is also nominated (Section 3.5).
- Many building materials and microbial organisms respond to relative humidity, rather than to absolute humidity. Even small amounts of water vapour at low temperatures can raise relative humidity to problematic levels of 50-70%. Health risks and damage to the building fabric can occur before relative humidity reaches 100% (or dew point) when condensation begins (Section 3.6).
- The tendency of hygroscopic materials such as timber and masonry to take up water vapour as relative humidity rises can moderate conditions by temporarily storing water vapour and releasing it later when drying conditions prevail. (Section 3.7)
- Persistent condensation can create nuisance, damage or hazards similar to those caused by failures to prevent intrusion of rain or groundwater (Section 3.8)

4 Climate

4.1 Climate Classifications

When dealing with condensation, there are at least two climates to consider: one that the weather constructs outdoors and the other created accidentally or by design indoors. 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 fresh air from the outdoors 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 4.1) will set conditions for what happens in the interstitial spaces of the building envelope. This chapter deals firstly with the climate outdoors and briefly with the range of indoor conditions which can influence condensation risk.

Figure 4.1 – Outdoor and indoor climates



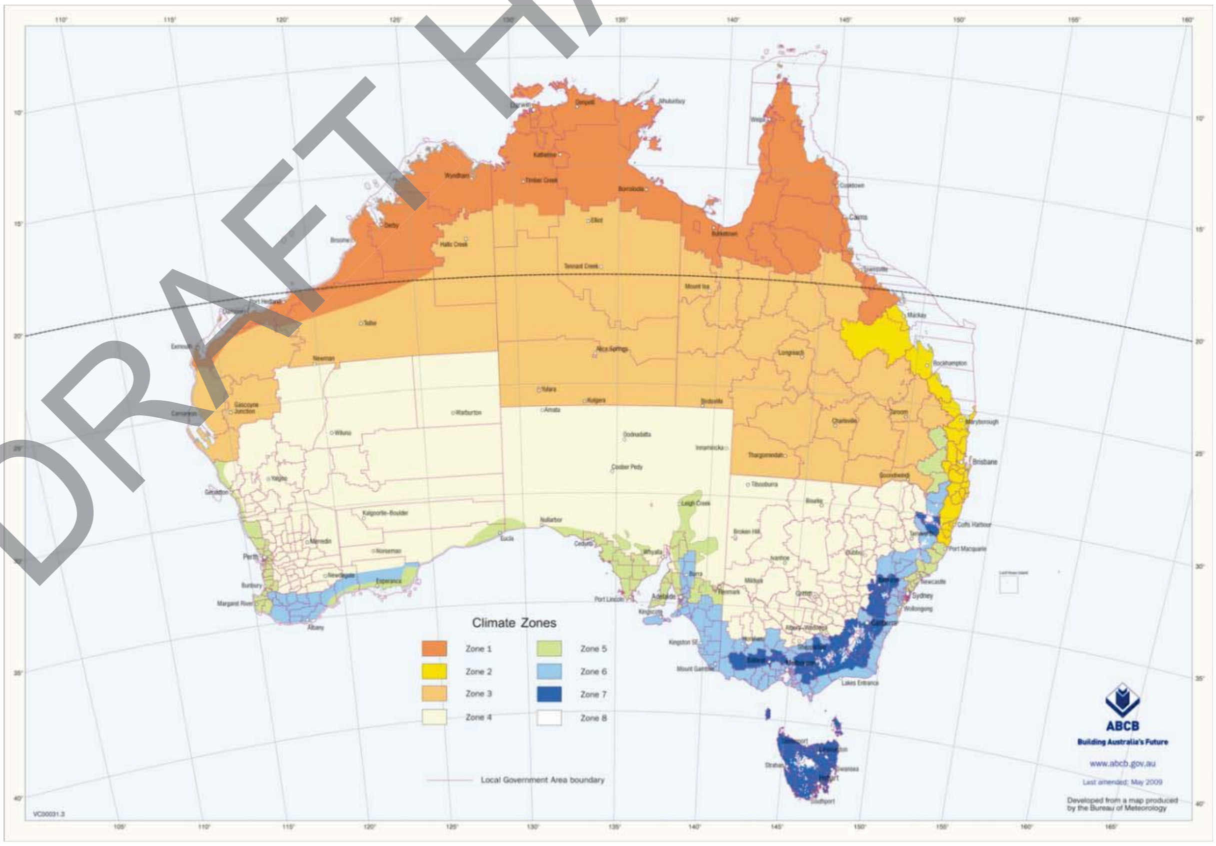
The notion of climate is an attempt to discern some order in the vagaries of the weather. Although the characterisation of a climate does not settle the question of whether to take an umbrella tomorrow, it can indicate broadly what to expect from season to season and from month to month in a given place. 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 will feel too cold under outdoor conditions for all of the year or most of it. 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 BCA energy efficiency provisions (Figure 4.2).

Figure 4.2 – BCA climate zones for thermal design
(Figure A1.1 in Volume One and Figure 1.1.4 in Volume Two)



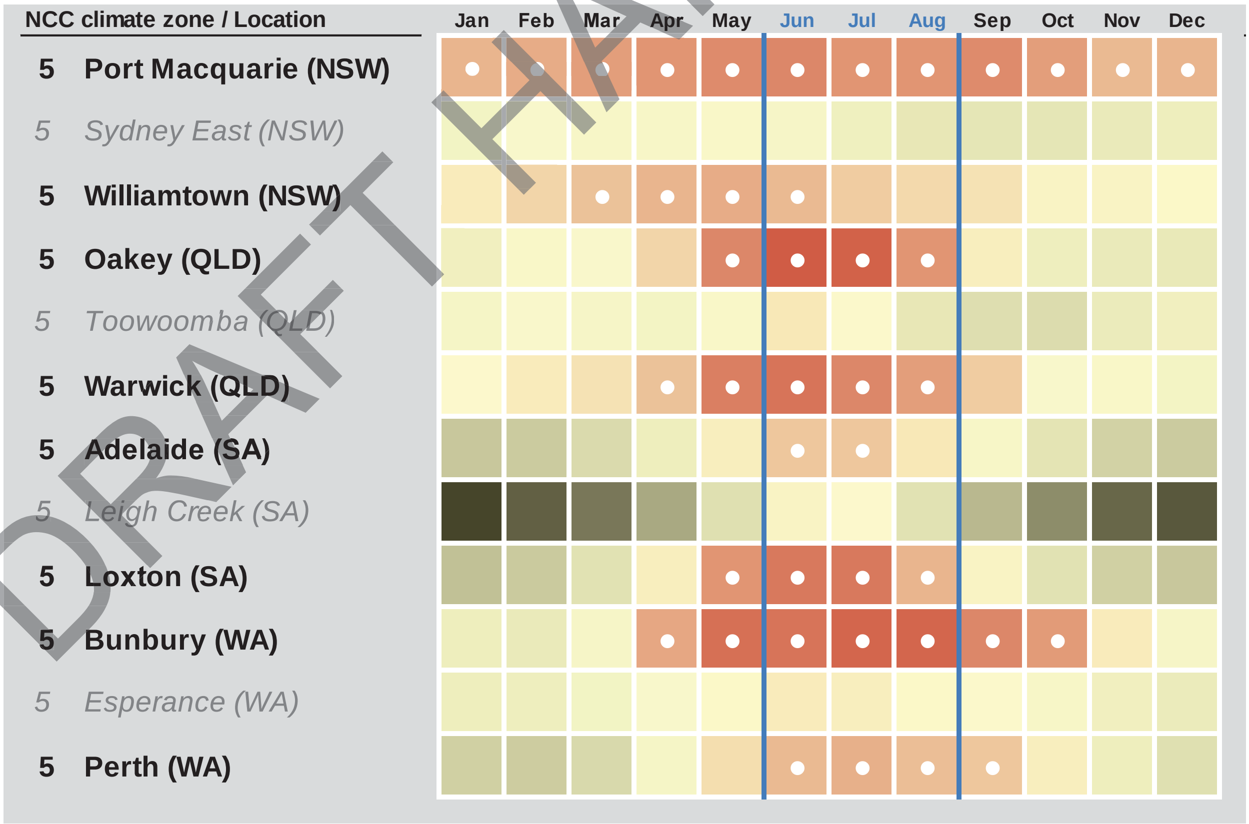
NCC Alert:

The eight BCA 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 BCA designations only by climate zone 8.

Developed with an emphasis on defining the desirable thermal characteristics of building envelopes, the eight BCA climate zones are not reliable indicators of condensation risk in buildings. Figure 4.3 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 BCA climate zone. The numerical values behind this assessment, covering a total of 160 locations across all States and Territories are provided in Appendix A.2.

Figure 4.3 – Comparative outdoor condensation potential in 12 locations in BCA climate zone 5

(Blue column borders highlight winter months of June, July and August)



NCC climate zone / Location	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
5 Port Macquarie (NSW)	●	●	●	●	●	●	●	●	●	●	●	●
5 Sydney East (NSW)												
5 Williamtown (NSW)			●	●	●	●						
5 Oakey (QLD)					●	●	●	●				
5 Toowoomba (QLD)												
5 Warwick (QLD)				●	●	●	●	●				
5 Adelaide (SA)						●	●					
5 Leigh Creek (SA)												
5 Loxton (SA)					●	●	●	●				
5 Bunbury (WA)				●	●	●	●	●	●	●		
5 Esperance (WA)												
5 Perth (WA)						●	●	●	●			

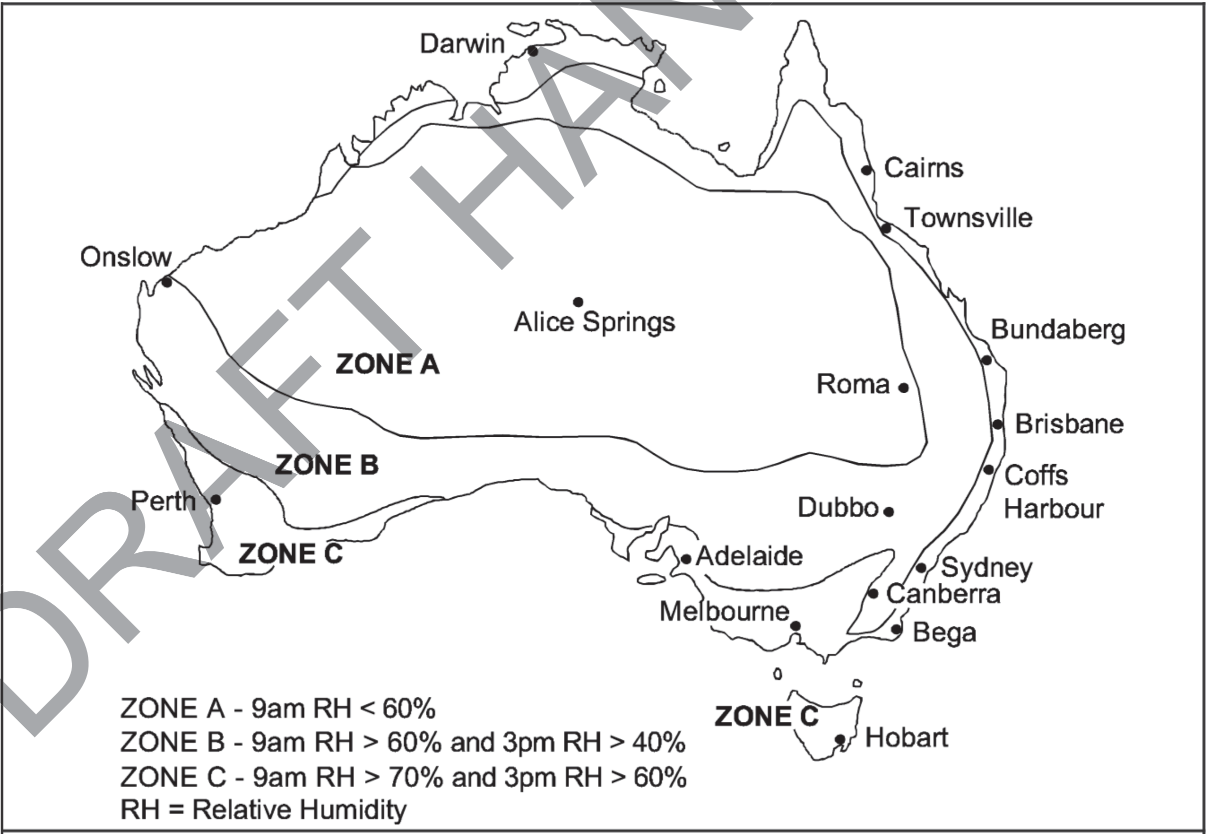
Figure 4.3 uses Bureau of Meteorology data to compare the average (or mean) minimum temperature in each month with the average dew point temperature for that month. Where the minimum temperature falls to or below the dew point, the table cell contains a white dot on a

red-brown background. The intensity of the red-brown colouring indicates how far the temperature falls below dew point. Months without dots have minimum temperatures above dew point but any red-brown colouring indicates a close approach to the dew point. Grey-green colouring increases the higher the minimum temperature is above dew point in each month.

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 4.3 also highlights that conditions favouring outdoor condensation are not necessarily confined to the colder winter months of June, July and August.

The BCA uses a second, and older, classification system in describing Acceptable Construction Practice for sub-floor ventilation. F1.12 in BCA Volume One and 3.4.1.2 in BCA Volume Two identify three “climatic” zones based on seasonal relative humidity and designated as zones A, B and C (Figure 4.4).

Figure 4.4 – BCA climatic zones based on relative humidity for sub-floor ventilation
(Figure F1.12 in Volume One and Figure 3.4.1.2 in Volume Two)



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

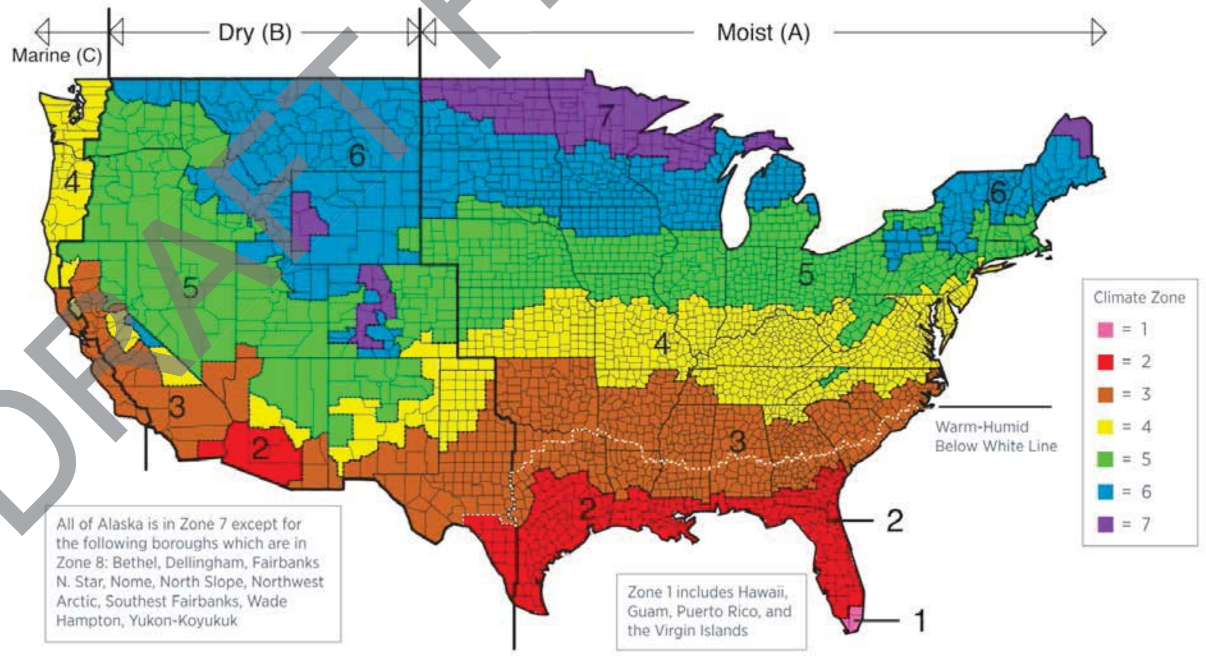
The three climatic zones for sub-floor ventilation requirements call for greater sub-floor ventilation potential where higher relative humidity is anticipated. While the classifications depend directly on relative humidity, the criteria are broadly defined and assessed for a single, worst-case month. Comparing Figure 4.3's varying outcomes for Sydney, Adelaide and Perth (all in climatic zone C) suggests that this classification system does not discriminate condensation potential closely enough to be used outside of its current BCA context.

4.2 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 United States, for example, the International Energy Conservation Code (IECC) identifies eight temperature-oriented zones which can be sub-divided by three moisture designations, allowing as many as 24 classifications of temperature and moisture conditions.

Figure 4.5 shows the application of the system, county by county, to the contiguous United States (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 4.5 – International Energy Conservation Code (IECC) climate regions for the USA
(Source: Building America 2010)



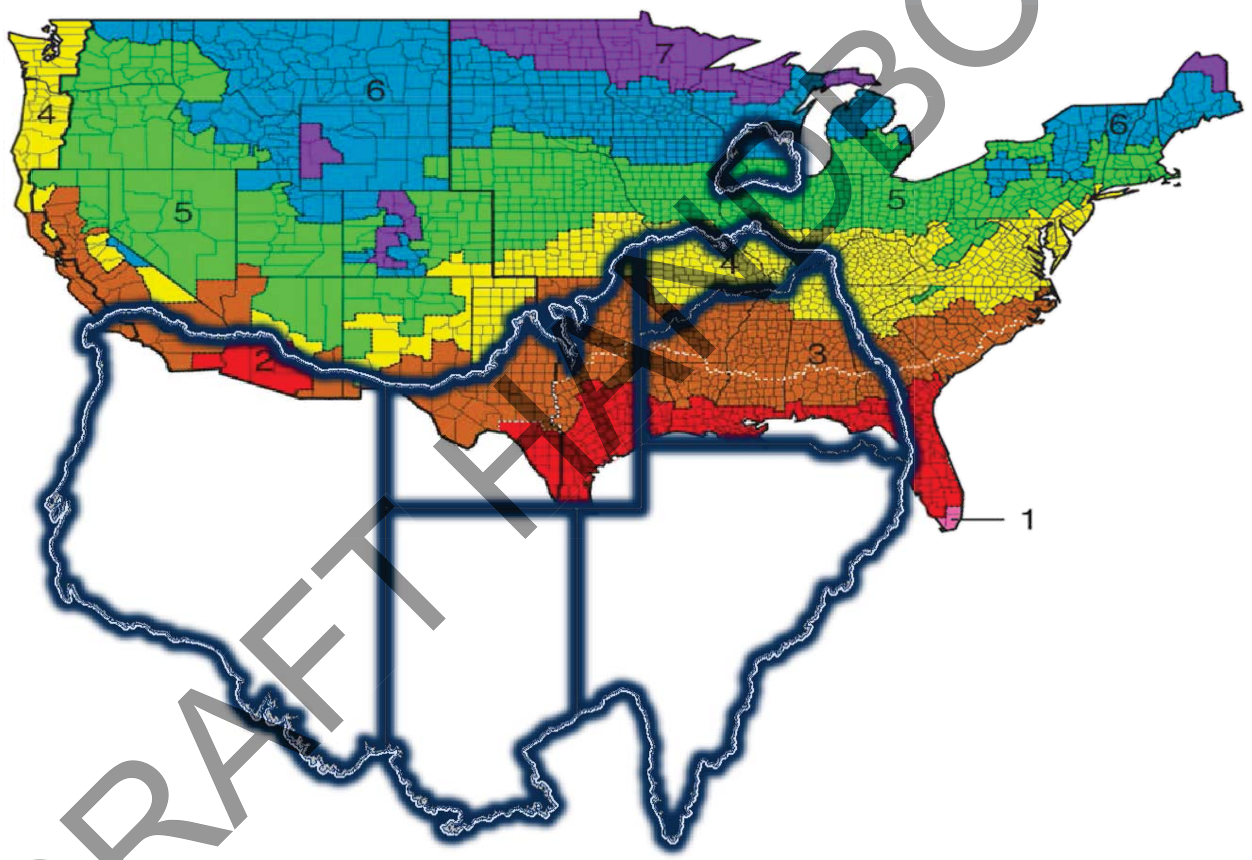
All of Alaska is in Zone 7 except for the following boroughs which are in Zone 8: Bethel, Dellingham, Fairbanks N. Star, Nome, North Slope, Northwest Arctic, Southest Fairbanks, Wade Hampton, Yukon-Koyukuk

Zone 1 includes Hawaii, Guam, Puerto Rico, and the Virgin Islands

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. 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 of 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 4.5) 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.

Figure 4.6 – Australian land mass overlaid on the contiguous United States at equivalent latitudes

(The side-to-side placement provides an approximate alignment of moist and dry regions.)



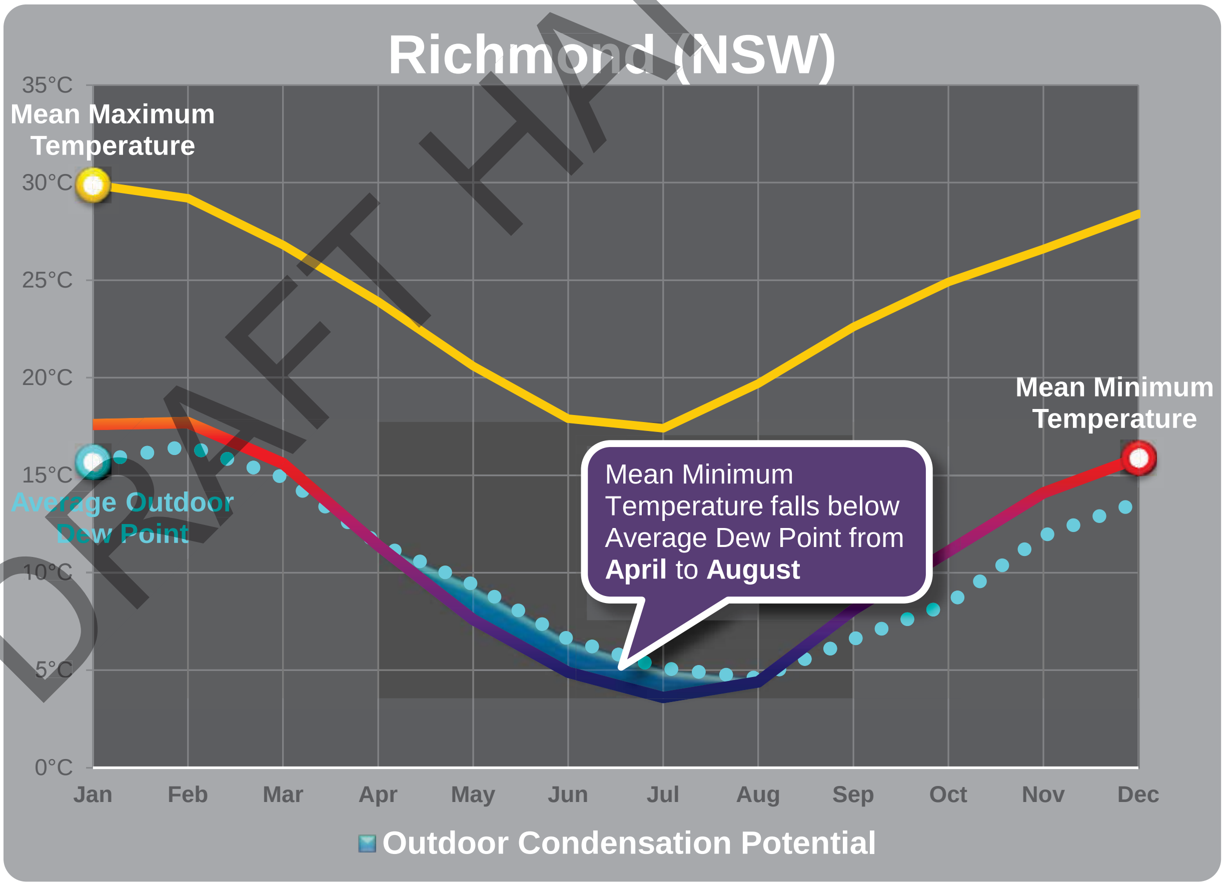
Although latitude alone does not account for climatic similarities, the true-to-scale comparison of the Australian and US maps in Figure 4.6shows that the maps overlap mainly in regions designated in the United States as Hot or Mixed climates (Humid on the east and Dry on the west). Australia's greater latitude span (33° compared to 25° or a distance of about 900 km) and its closer proximity to the Equator (10° rather than 25°) tend to extend the meaning of the terms "Hot" and "Humid".

In any case, systematic classification of climates needs to be matched by consensus on indoor and outdoor conditions to be applied in risk calculation methods. Current calculation methods and software tools are very sensitive to the assumed environmental conditions. For the US, ASHRAE Standard 160-2009 (outlined in Chapter 6) offers, according to its title, “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”.

4.3 Comparing Outdoor Condensation Potential across Australia

Without an established consensus, Australian building practitioners may still find useful information in local resources. Figure 4.7, 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.

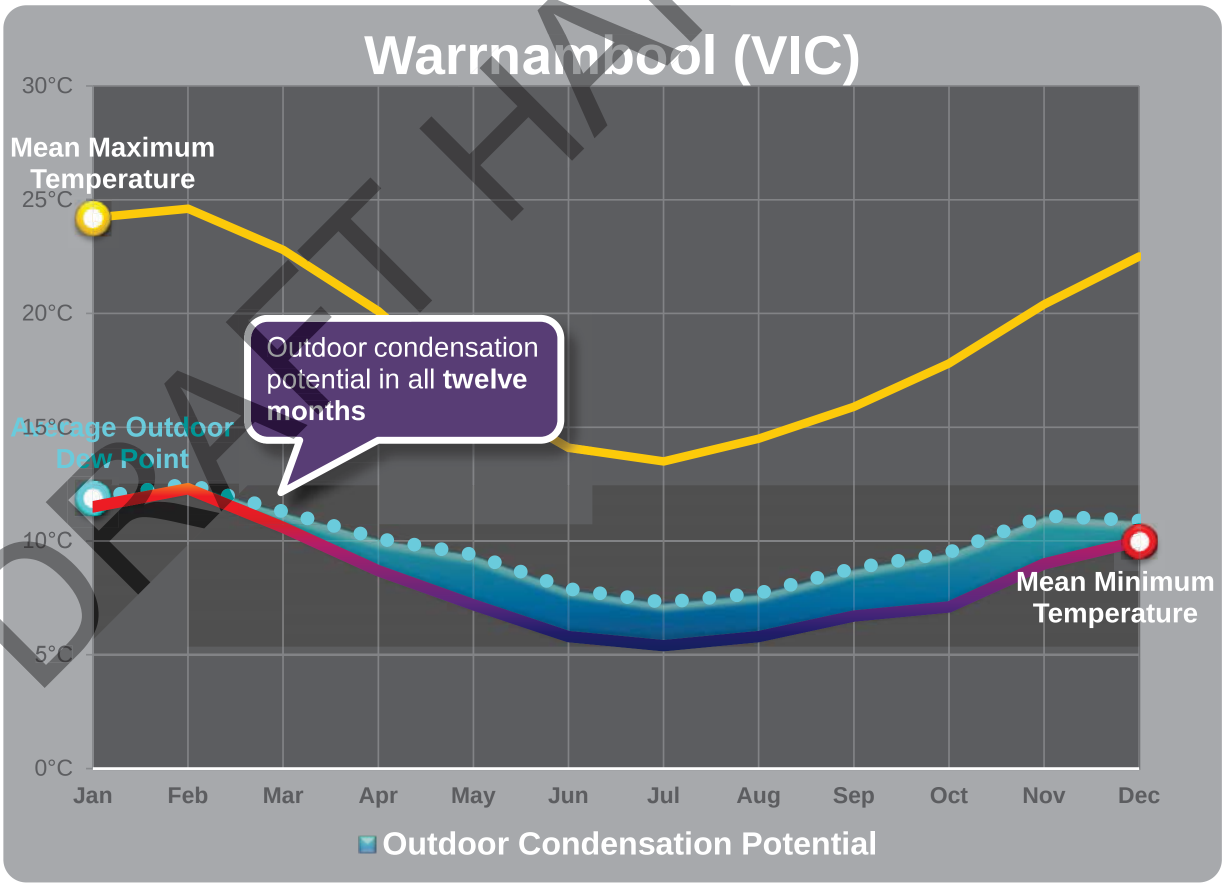
Figure 4.7 – Comparison of monthly mean minimum temperatures and average dew points (outdoor condensation potential)



The BOM statistics provide (among other details) mean minimum and mean 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 4.7 and Figure 4.8 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 4.8 shows, the potential need not be limited to the colder months of the year. In some locations, the critical 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 4.6, where the effects of likely indoor water vapour loads for dwellings are also considered.

Figure 4.8 – Outdoor condensation potential spanning all 12 months

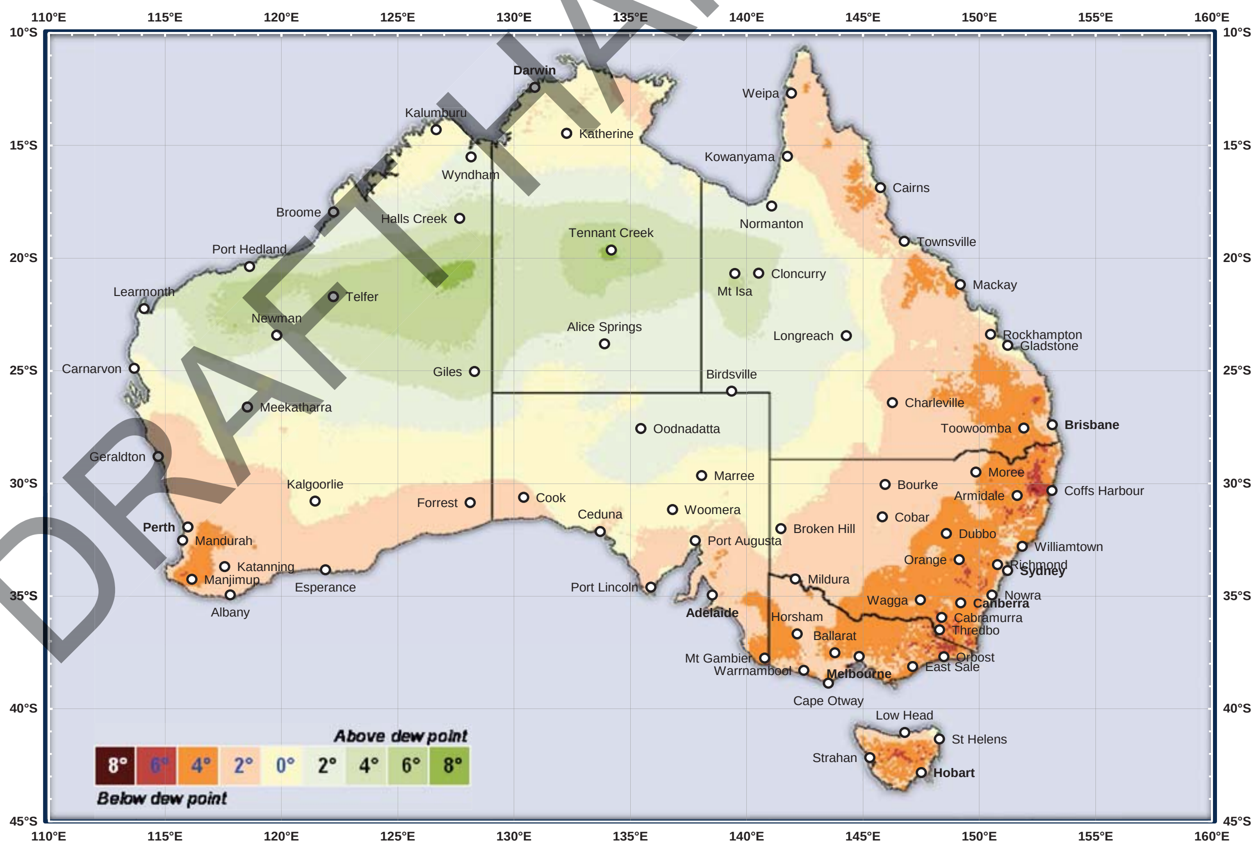


The comparison illustrated in Figure 4.7 and Figure 4.8 can identify the month with the greatest potential for outdoor condensation and how many months are affected in each year, under average conditions. This is a rudimentary evaluation that does not take into account the indoor environment and building fabric arrangements that can cause problems inside a building or in the interstitial layers and spaces of its envelope. Nevertheless, it may offer a first basis for characterising the contribution of local climate to condensation risk in various locations across the country by applying primary data.

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 condensation risk (Figure 4.9 and Appendix A.1 for larger version). The map shows the approximate margin between the minimum temperature and the average dew point in the worst case month for each part of the grid. The further the minimum temperature falls below dew point, the greater the potential for outdoor condensation in at least one month.

The first purpose of the map is to alert practitioners and building users to locations where the outdoor climate warrants closer attention to condensation risks. In those cases, the methods outlined in Sections 4.4 and 4.6 can extend the assessment for a particular location.

Figure 4.9 – Exploratory map of comparative outdoor condensation risk
(for use with Condensation in Buildings Information Handbook only)



Applying this test to 160 specific locations shows that 95 of them, drawn from all BCA climate zones, have potential for outdoor condensation in at least one month. In such areas, building project participants might consider all of the following steps (at least):

- detailed analysis of the local climate (possibly using the method in Section 4.4 or a preferred alternative);
- evaluation of the likely worst case internal water vapour loads and air leakiness of the building envelope;
- minimising rain exposure and perpetual shading of envelope walls and lower storey roofs;
- selecting façade and roofing systems more robust against flaws in construction;
- 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;
- exhausting indoor water vapour sources directly to the outside;
- enhancing ventilation arrangements that can dilute indoor water vapour levels;
- employing building pressurisation through mechanical systems to limit unwanted water vapour migration towards cooler surfaces.

Drafting Note:

Although based on a simple principle, the method outlined and illustrated in Section 4.4 is offered only as an exploratory approach with a request for comment from interested researchers and practitioners on its validity and usefulness.

The map in Figure 4.9 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.

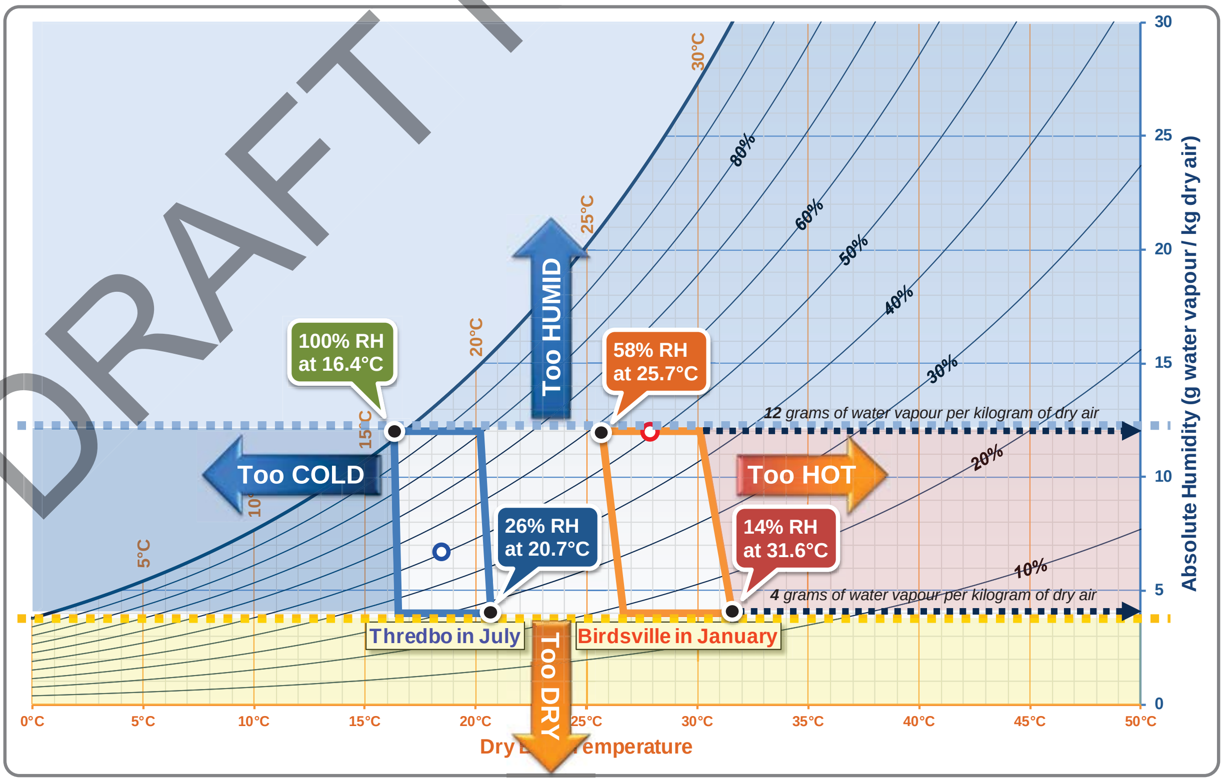
4.4 Assessing Local Outdoor Climate

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 Section4.3. 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 4.10 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% relative humidity 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 absolute humidity (4-12 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 4.10 – Range of human comfort limits for Australian climates (outdoors)



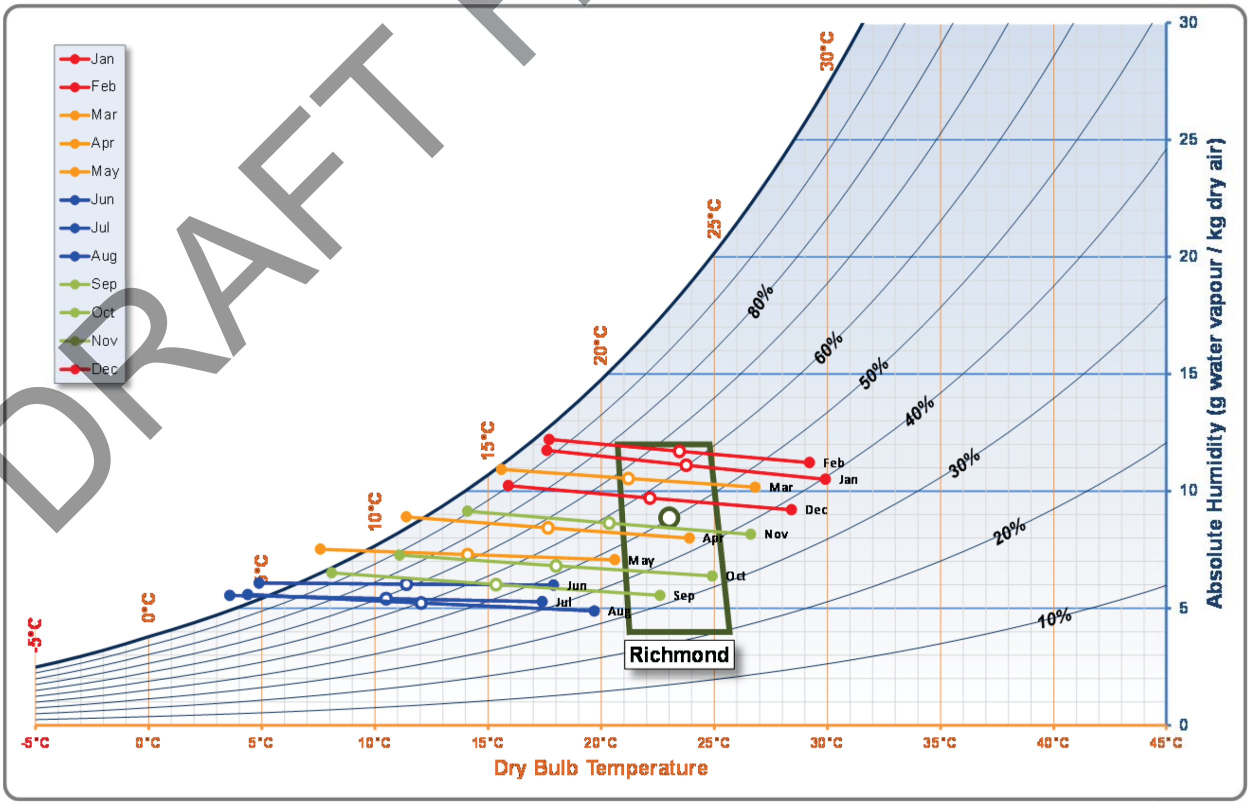
Examining which of the curving relative humidity lines pass through the two comfort zones provides some useful observations. The Birdsville case suggests that building occupants acclimatised to summer in a hot-dry climate may tolerate relative humidity lower than 20% and up to about 60% (from bottom-right corner of the comfort zone up to top-left). People here would notice discomfort before relative humidity reached levels likely to promote mould growth on building surfaces. By contrast, adaptation to the cold Thredbo winter climate allows relative humidity approaching 100% to feel acceptable. In colder climates, problematic relative humidity 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. In Figure 4.11, 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:

1. the average (or mean) minimum temperature for the month and the mean dew point temperature at 9am (which, it is recognised, might not occur at the same time);
2. the mean maximum temperature and the 3pm dew point temperature.

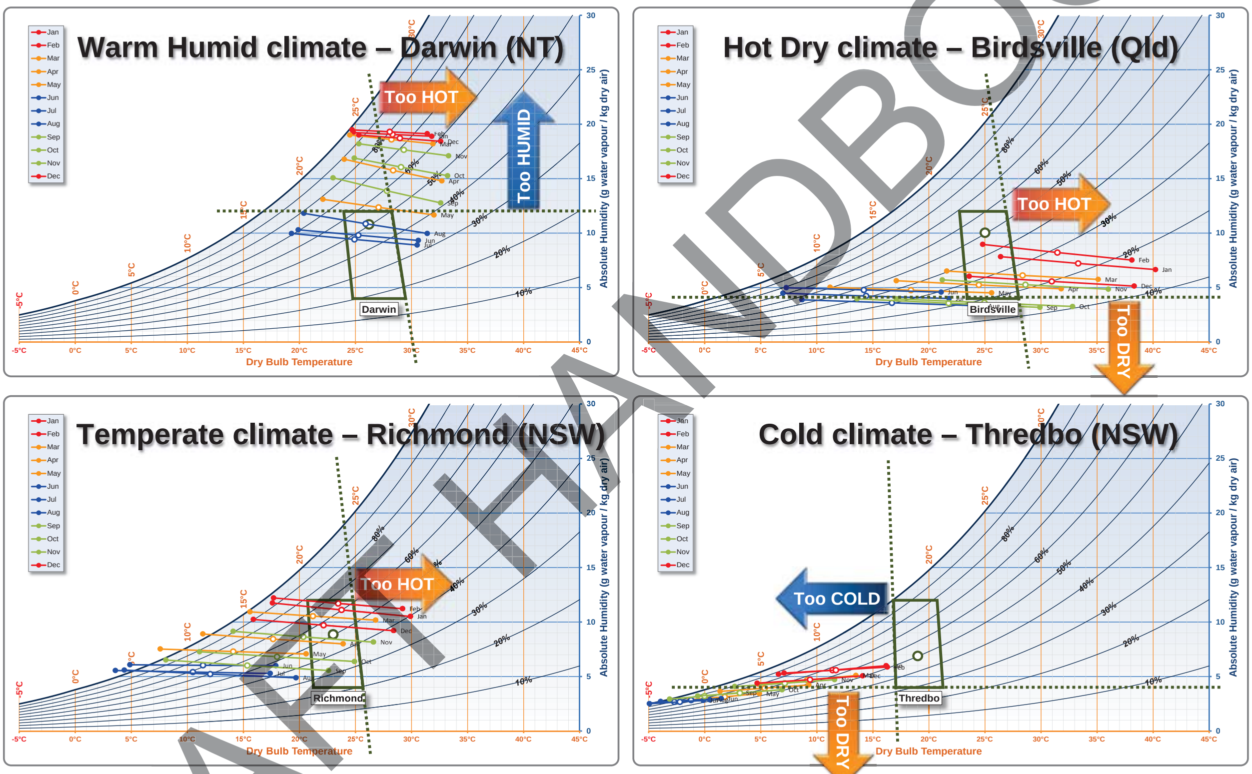
A midpoint on each line, with a white centre, shows the average dew point temperature for the month and the average temperature.

Figure 4.11 – 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 4.11 are examined further after first comparing it, in Figure 4.12, with examples of the other three basic climate types.

Figure 4.12 – Characteristics of the Four Basic Climate types



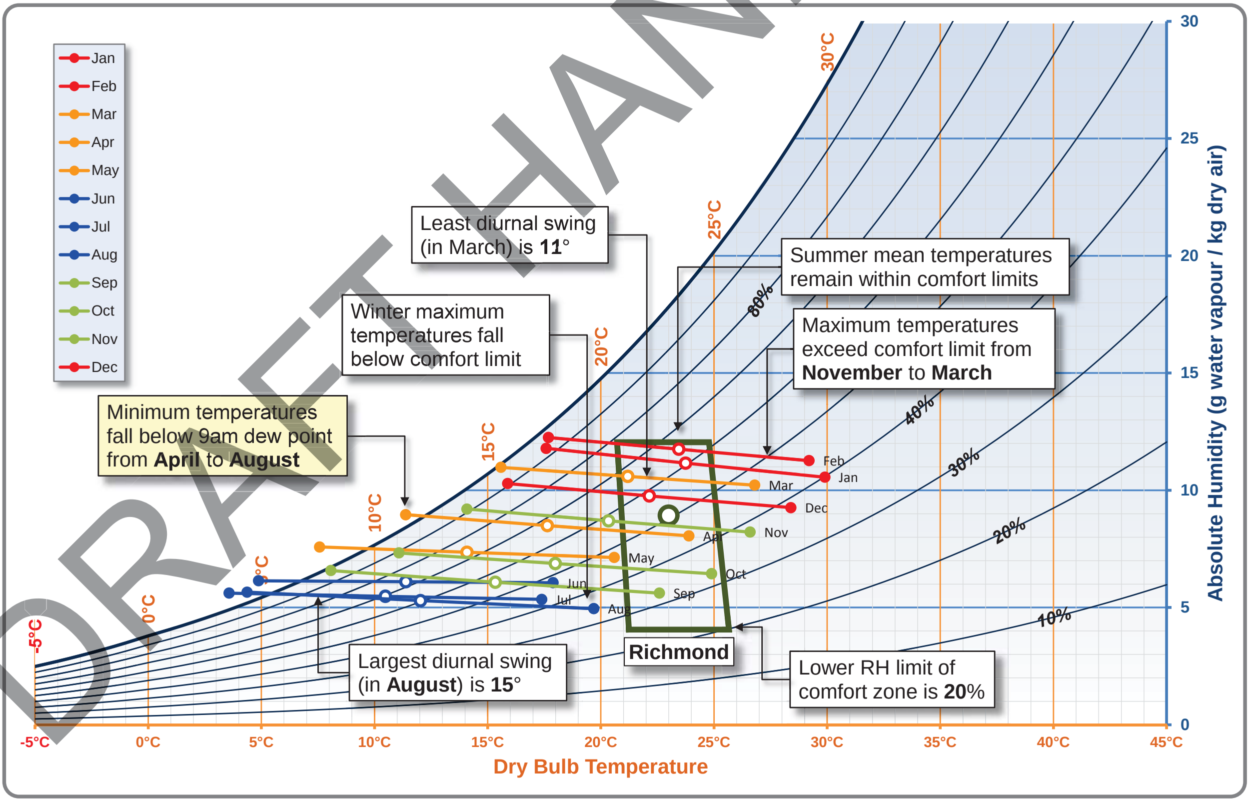
Distinct differences between the four climate types are quickly evident in Figure 4.12 where the placement, spacing, length and slope of the monthly lines are all significant. In considering what such charts suggest about the nature of the climate and possible responses by building occupants seeking 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 will be uncomfortably high or too low);
- the vertical separation of lines (indicating monthly or seasonal variations in humidity levels);
- the slope of lines from left to right (indicating rising or falling humidity levels between mornings and afternoons);

- the sideways extension of lines to the left and right of the comfort zone (indicating when temperatures will be cooler or warmer than preferred and likely to lead to use of heating or cooling);
- the 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 increase the potential for overnight condensation);
- the horizontal spread of lines (indicating temperature variations between seasons).

Figure 4.13 returns to the Richmond (NSW) climate and highlights some of the temperature characteristics likely to influence heating and cooling choices, perceptions of uncomfortable relative humidity 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 4.7, the overnight minimum temperature here is compared with the 9am dew point, rather than the average dew point.

Figure 4.13 – Annotated Climate Analysis for Richmond (NSW) – Mild Temperate



Least diurnal swing (in March) is **11**°

Winter maximum temperatures fall below comfort limit

Minimum temperatures fall below 9am dew point from **April** to **August**

Summer mean temperatures remain within comfort limits

Maximum temperatures exceed comfort limit from **November** to **March**

Richmond

Largest diurnal swing (in **August**) is **15**°

Lower RH limit of comfort zone is **20**%

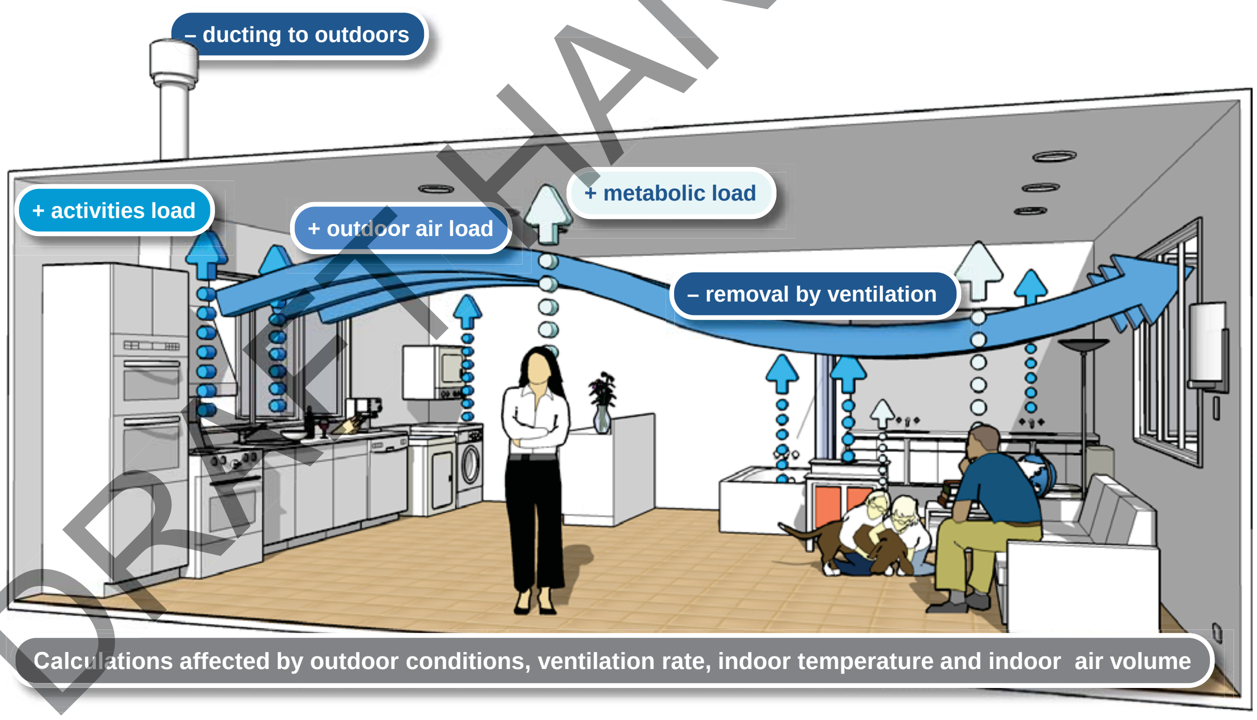
This graphical approach has the advantage of assembling information about average outdoor conditions in all 12 months in a compact format. The same approach is extended in Section 4.6 to address the likely impact of water vapour levels in the indoor climate.

4.5 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 uncommon in Australian houses and especially during the months when heating is desired. The water vapour content of the outdoor atmosphere is the starting point for indoor humidity conditions during the heating season.

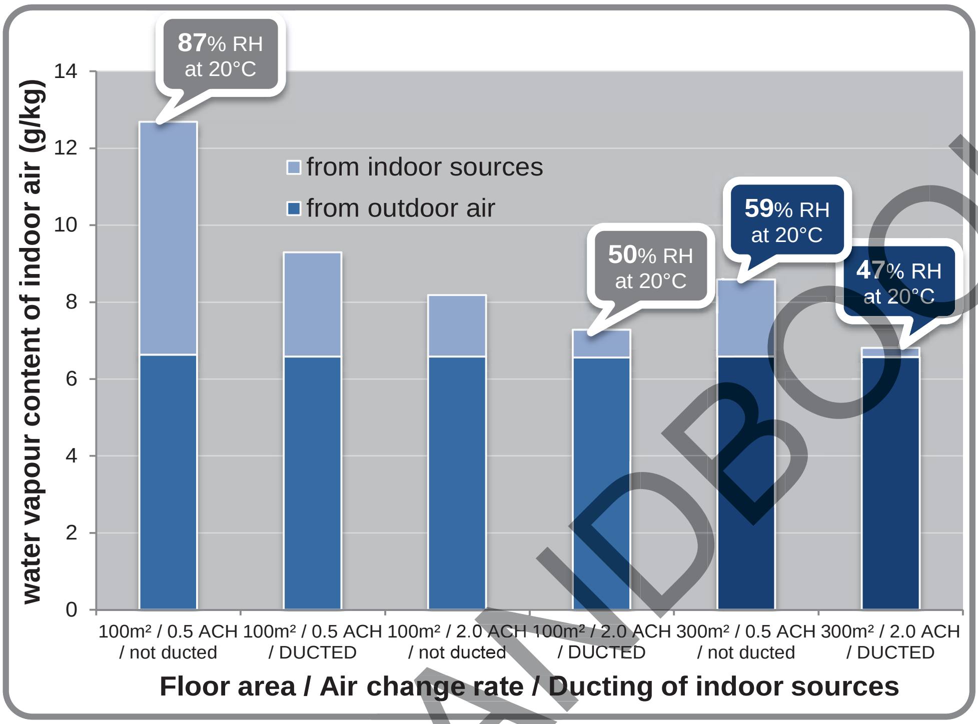
For dwellings, daily average water vapour levels indoors will depend, at a minimum on what arrives with incoming outdoor air for ventilation, what is added from sources indoors, how much can be diverted directly outside and the rate of removal by ongoing ventilation, as highlighted in Figure 4.14. Approximate daily rates for water vapour release in residential situations appear in Figure 4.16.

Figure 4.14 – 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 and 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 4.15.

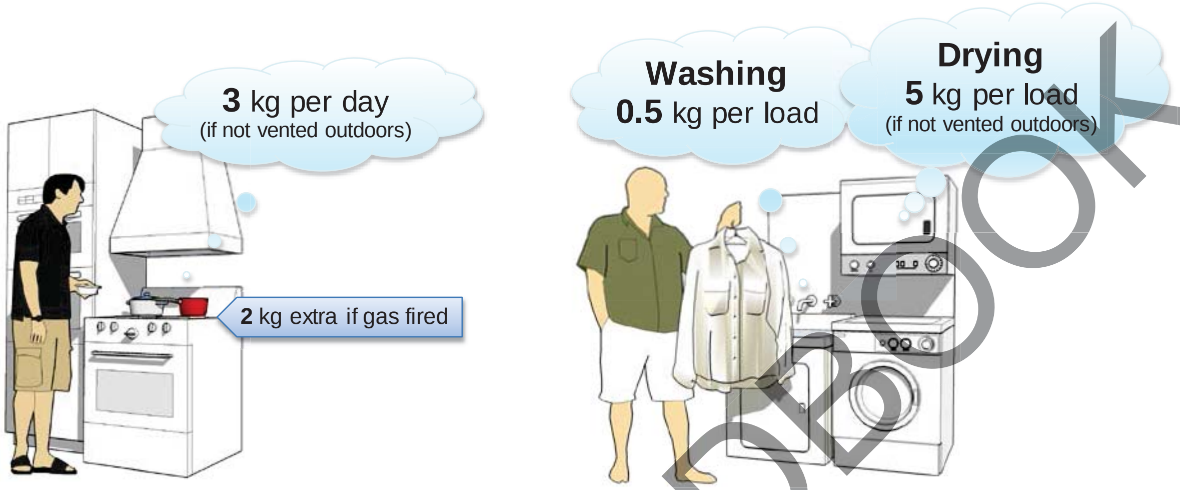
Figure 4.15 – Impact of indoor volume, air change rate and ducting of sources on indoor humidity



The first four columns in Figure 4.15 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 dwelling (the 10 kg average value is based on typical rates of release shown in Figure 4.16). 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 fresh air ventilation rates, however, make considerable differences to the average water vapour content indoors (shown by the overall height of each column).

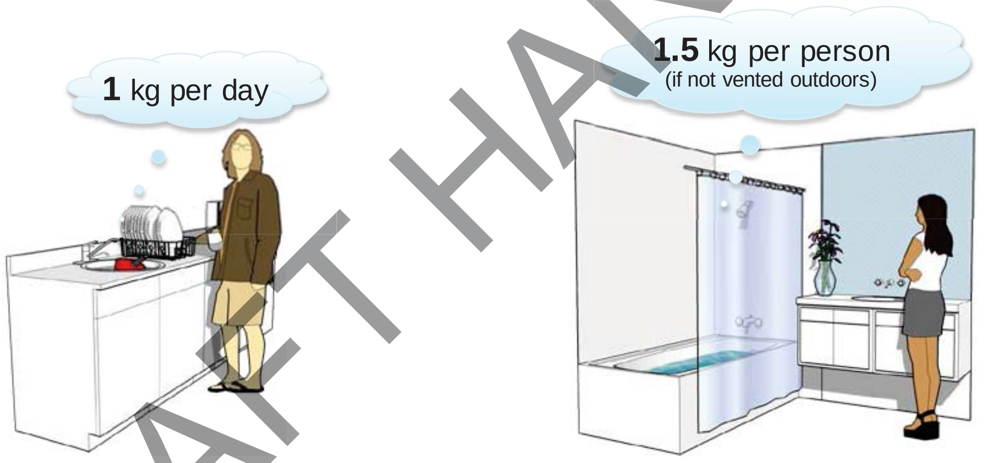
Whatever is not ducted to the outdoors or carried away by ventilation will be dispersed through the moist air volume in the building. In practice, it is unlikely that perfect mixing will occur, particularly when bathrooms and laundries are often behind closed doors. Indoor sources, concentrated in particular 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 releases indoors (as demonstrated by the varying examples in Figure 4.15). This approach is adopted in Section 4.6, 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 4.16 – Indoor sources of water vapour in dwellings and rates of release
(Source: BRANZ 2012)



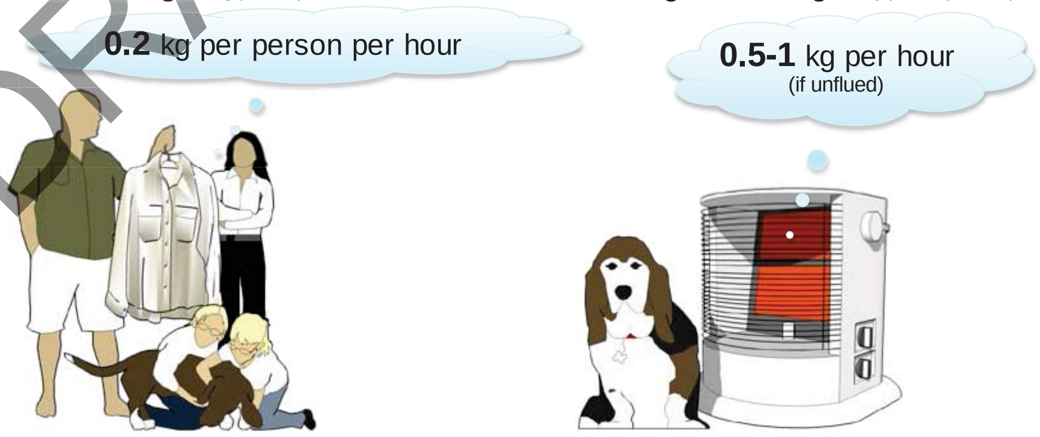
Cooking: 5 kg per day – unvented, gas fired
2 hours of cooking per day

Laundering: 0.6 kg per day – unvented
washing every 5 days, drying every 10 days



Dishwashing: 1 kg per day

Bathing/Showering: 6 kg per day for 4 people – unvented



Occupants: 5.5 kg per day for family of four
absent / active / asleep 8 hours each

Gas heating: 4 kg per day – if unflued
(dog not included)

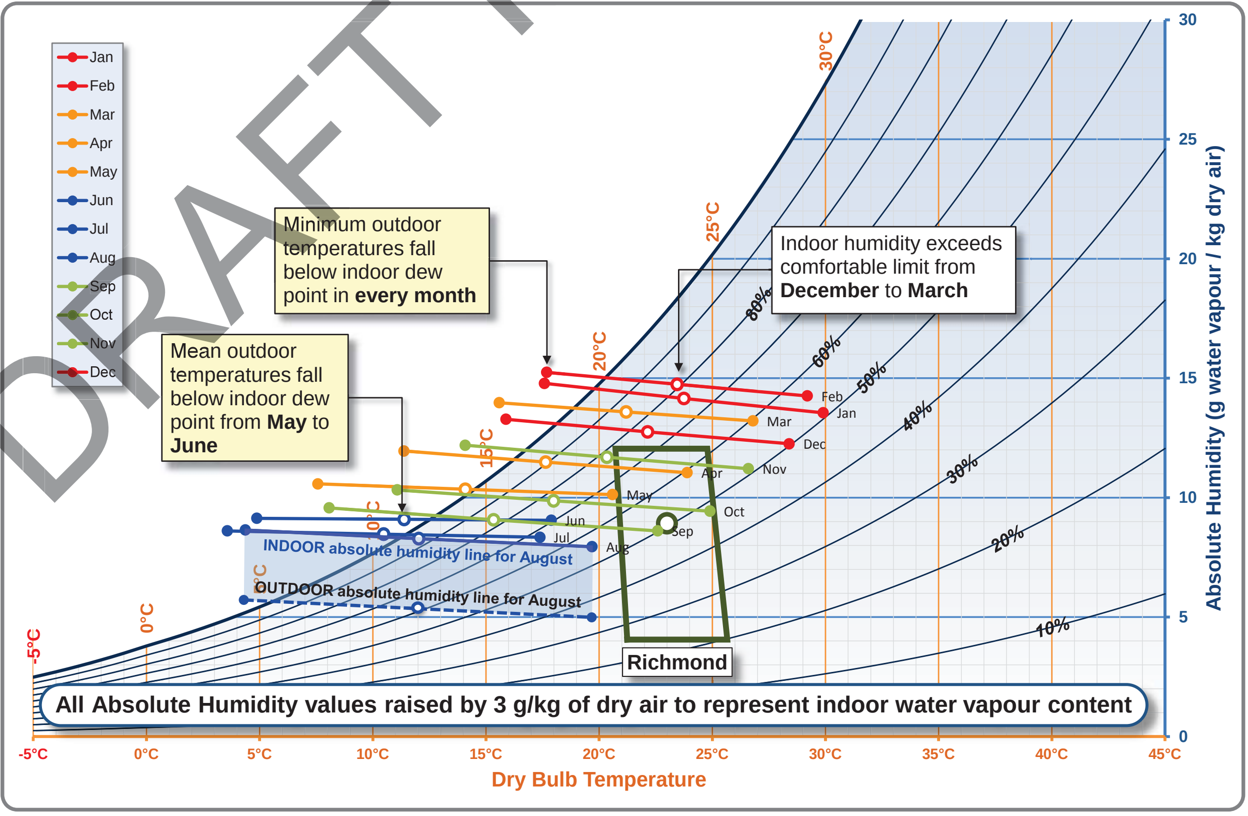
Figure 4.16 suggests that occupants could release a total of about 5.5 kg of water vapour per day if two adults and two children (each releasing half the amount of an adult) were absent for eight hours a day, active for eight and asleep for the remaining eight hours. Their domestic activities might contribute another 4.5 kg if releases from gas cooking and showering were discharged outside (with 70% effectiveness), clothes drying ducted (with 90% effectiveness) and any gas heater fully flued.

The daily total of 10kg for such pattern of occupancy and activity matches the design moisture generation rate recommended in ASHRAE Standard 160-2009 for a household of four (occupying three bedrooms). The 10 kg rate in ASHRAE Standard 160-2009 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."

4.6 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 4.4 to illustrate what might happen when moist indoor air encounters building surfaces which have been cooled to temperatures close to those outdoors. Figure 4.17 shows the Richmond (NSW) example from Figure 4.13 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.

Figure 4.17 – Absolute Humidity values adjusted for indoor load – Richmond (NSW)



Minimum outdoor temperatures fall below indoor dew point in **every month**

Mean outdoor temperatures fall below indoor dew point from **May** to **June**

Indoor humidity exceeds comfortable limit from **December** to **March**

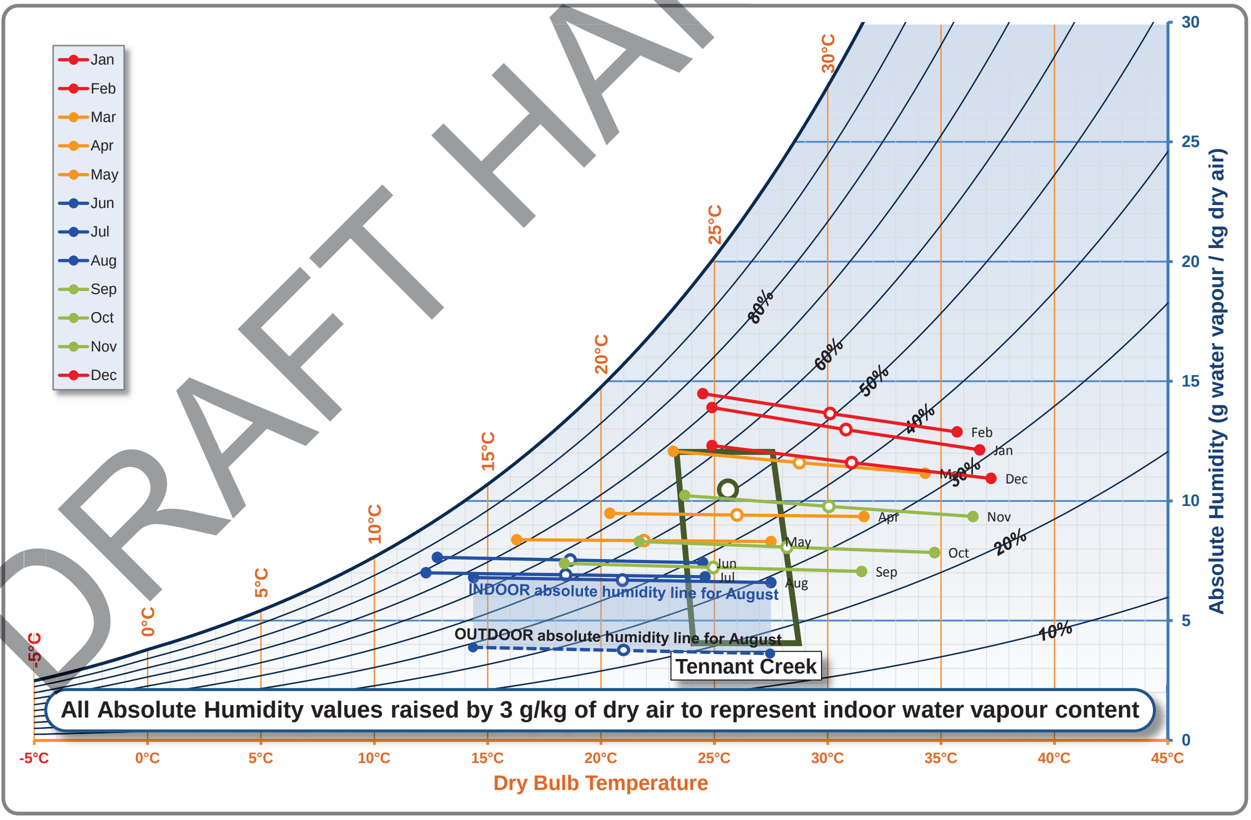
All Absolute Humidity values raised by 3 g/kg of dry air to represent indoor water vapour content

In the adjusted version of the climate analysis chart, all absolute humidity values have been increased by a uniform 3g/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 relative humidity 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 4.18 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, relative humidity in the colder parts of the building fabric remains below 60%.

Figure 4.18 – Absolute Humidity Values adjusted for indoor load – Tennant Creek (NT)



The 3 g/kg increase to absolute humidity is suggested by analysis of 160 climates completed by the ABCB. In the alpine climates, the increase should be a 3.5 g/kg. Using a small dwelling size and low ventilation rate makes the result conservative for larger and better ventilated buildings. If this seems unnecessarily cautious, the 3 g/kg can be increased 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 load - to 20 g/kg - would also double the approximate increase in absolute humidity from 3° to 6° (or 7° for alpine climates).

The comparisons shown in Figure 4.17 and Figure 4.18 are straightforward to construct and use information readily available for download from BOM. For houses, they 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.

4.7 Climate in Summary

- Four basic climate types can be enough to categorise the main environmental factors which affect human comfort: warm humid climates, hot dry climates, temperate climates and cold climates (Section 4.1).
- Although the eight BCA climate zones for energy efficiency are variants of the four basic types, their definition did not depend strongly on the humidity conditions which influence condensation risk in buildings (Section 4.1).
- Although substantial effort has been made overseas to classify hygrothermal conditions over broad regions for building design and moisture control and to reach consensus on appropriate inputs to risk evaluation methods, similar information has not been assembled for Australia (Section 4.2).
- For a first indication of propensity to outdoor condensation in various places, local building practitioners can use monthly climate statistics from BOM. Comparing monthly mean minimum temperature with the average of the 9am and 3pm outdoor dew point temperatures will highlight months when dew is likely to form on outdoor surfaces and the intensity of the “risk” (Section 4.3).
- The ABCB has extended the same comparison across the country using gridded data sets from BOM to prepare a map of comparative outdoor condensation risk (Section 4.3).
- A more comprehensive view of climate characteristics in any one place can be assembled on a psychrometric chart using the same BOM data. The resulting chart can indicate seasonal patterns in temperature and humidity, likely periods of demand for heating and cooling and the extent of outdoor condensation over all 12 months (Section 4.4).
- For assessing condensation risk, indoor conditions can be considered as a distinct climate system due to the presence of indoor sources of water vapour and intentionally created temperature differences. Indoor water vapour levels are strongly influenced by outdoor conditions, ventilation levels and the management of indoor water vapour sources (Section 4.5).
- Despite differences in outdoor climates between geographic regions, the impact of a typical residential indoor climate on absolute humidity does not vary substantially between locations. Adjusting the absolute humidity used to assemble the charts discussed in Section 4.4 can highlight whether there is a potential for condensation or excessive relative humidity in the cooler parts of the building fabric when indoor water vapour finds its way there (Section4.6).

5 Dry Buildings

5.1 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 5.1).

Figure 5.1 – 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 5.1 and Figure 5.2 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 relative humidity. Outside, an active weather system remains at work. Rain falls, humidity drifts, temperatures go up and down, walls and roofs move between sun and shadow and the wind creates a spectrum of varying air pressures as it blows and gusts over surfaces, corners and edges. Between these two environments, the fabric of the building enclosure carries a constant traffic of heat, air, water and water vapour, which is seeking to redress imbalances on each side. While the driving forces cannot be denied, unwanted movements can be diminished, diverted, detained or delayed to advantage through careful design and construction of the building envelope.

NCC Alert

"Envelope" is a defined term for the energy efficiency provisions of the NCC, with definitions that vary slightly between Volumes One and Two. Its usage in the NCC focuses mainly on the enclosure of spaces which are artificially heated or cooled ("*conditioned"* spaces) or likely to be because they are deemed to be "*habitable"*. Since the Handbook deals with condensation risks not directly regulated by the energy efficiency provisions, "envelope" here may refer to parts of the building enclosure not captured by the NCC definitions.

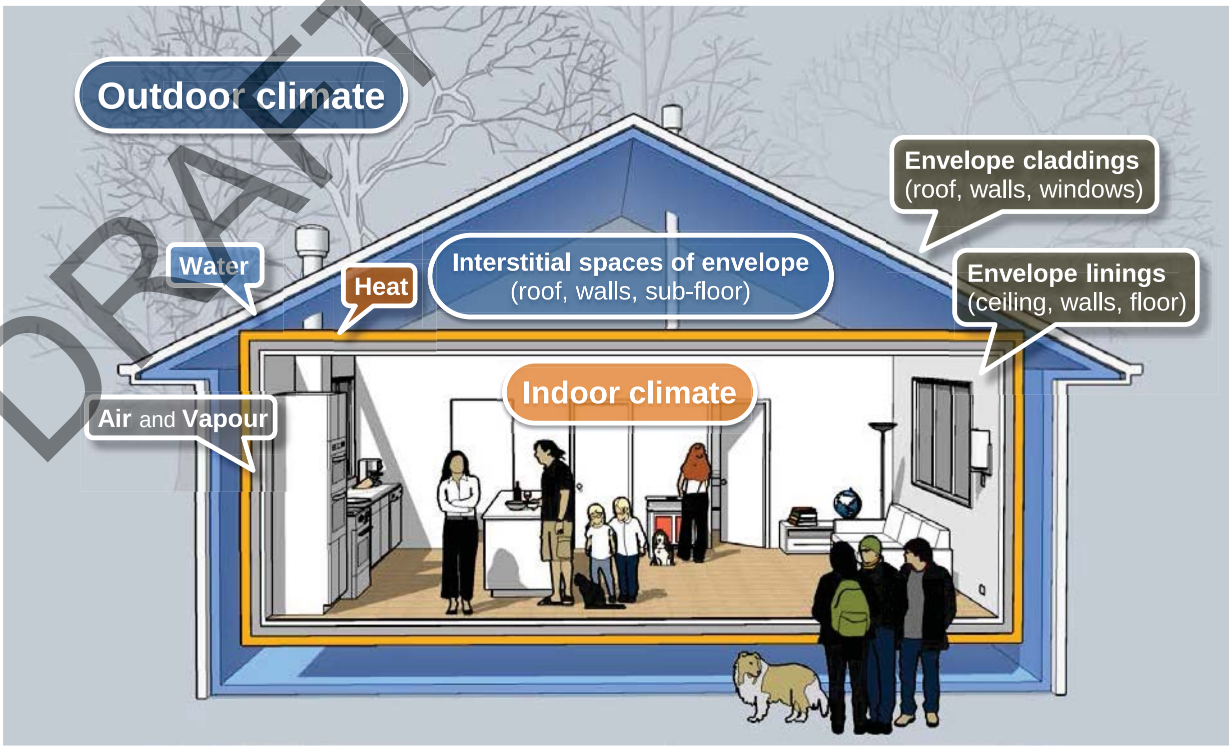
Figure 5.2 – Building envelope to sustain preferred indoor climate

In Figure 5.2, a blue dotted line highlights the boundaries of an envelope which protects air conditioned office interiors from warm, humid conditions outside. (The ground floor facilities would have a separate envelope, due to different operating times and activities.) 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 relative humidity 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.
- **Heat**: Controlling the flow of heat is essential to keeping envelope surfaces above dew point and to sustaining an indoor climate with acceptable relative humidity levels.

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 5.3).

Figure 5.3 – 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 overlapping or joining occurs at every transition. One material might service several control functions. With these complexities, the notion of a layer might exist mainly in the designer's mind but it is a valuable discipline when designing and detailing to avoid condensation.

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. Thinking carefully about what separate control layers must achieve and where they run through the building envelope can highlight what each material in the building fabric should be doing, what some of them should not be doing and whether familiar practices and details are still suited to the new environment.

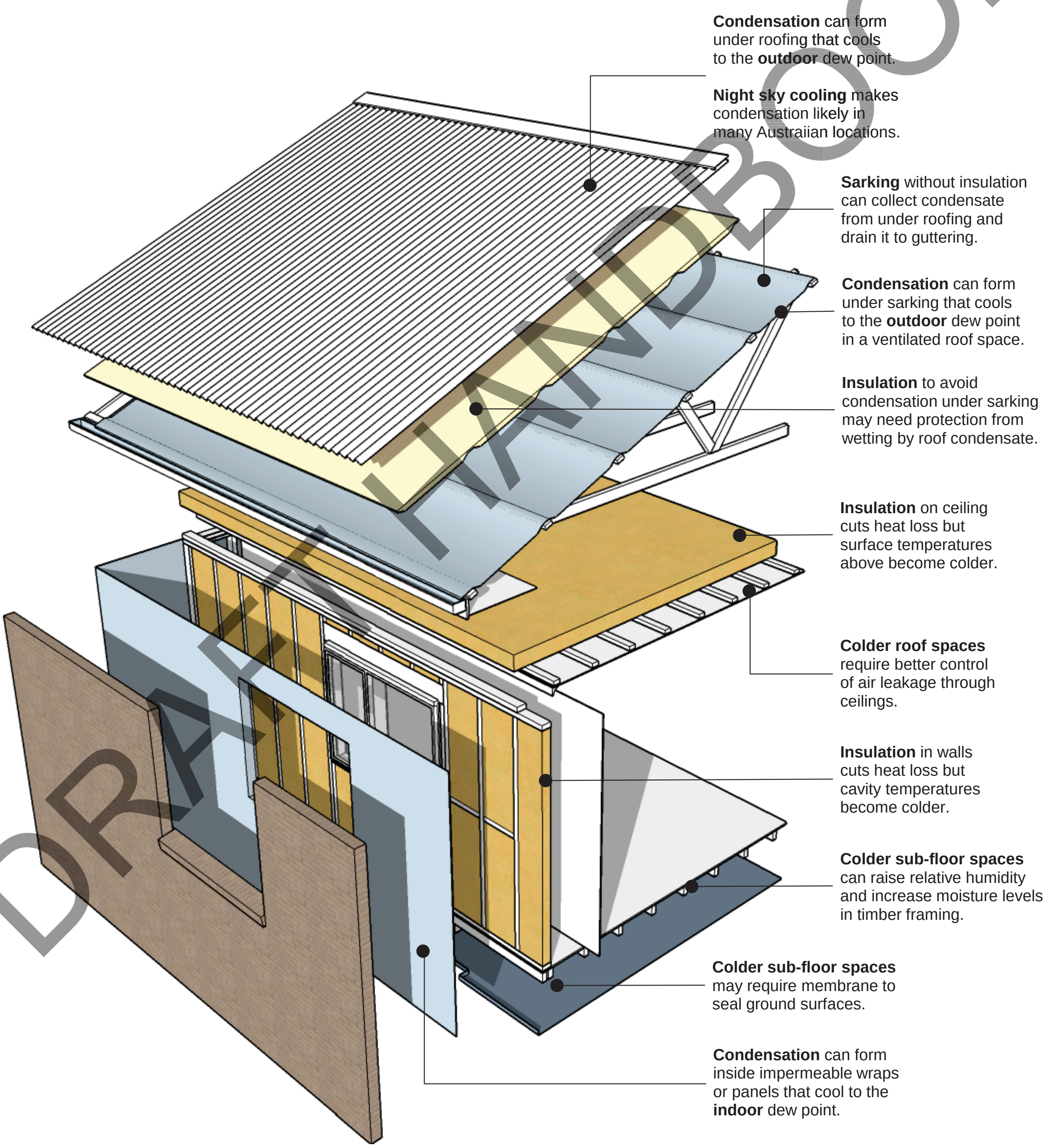
5.2 Changing Conditions inside the Building Envelope

Possible impacts of the NCC energy efficiency measures on condensation risk are acknowledged in the provisions but those regulatory changes are one part of broader trends that have converged in recent decades to increase risk factors. Some of those significant developments include:

- higher insulation levels that have reduced energy wasting heat flows by up to 90% but also limited opportunities for evaporation to dry the building fabric;
- the cooling of interstitial spaces due to the reduced heat leakage, raising relative humidity levels and the uptake of water vapour by hygroscopic materials such as framing timbers;
- increased water vapour resistance in claddings, linings and finishes, such as plastic and metal claddings, rendering of brickwork and vinyl wallpapers, which can reduce drying potential through walls;
- wider use of engineered timber products with lower moisture storage capacity and less mould resistance than the solid timber sections they replace;
- greater use of lightweight construction, also reducing the capacity of the building envelope fabric to detain moisture for later drying;
- reduced emphasis on effective ventilation of roofs and other interstitial spaces to dilute water vapour concentrations;
- lower ventilation levels in dwellings no longer occupied during the day, increasing indoor water vapour levels; and
- rapidly growing use of air conditioners for summertime cooling, creating out-of-season condensation risks in temperate and cooler climates and reversing the expected direction of water vapour flows during the course of the year.

The cumulative impact of these trends is that the interstitial spaces of the envelope will tend to have higher relative humidity 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 to leave. Figure 5.4 shows possible impacts on parts of an envelope typical of residential brick veneer construction, in the context of heating season condensation risk. These are risks in principle. How severe they actually are in practice will depend on the outdoor climate of the location, the indoor climate generated by the way the building is used and the qualities of the envelope provided to separate them. In any case, the risks are manageable once they are understood.

Figure 5.4 – Changes to interstitial envelope conditions for a typical brick veneer house



Condensation can form under roofing that cools to the **outdoor** dew point.

Night sky cooling makes condensation likely in many Austraiian locations.

Sarking without insulation can collect condensate from under roofing and drain it to guttering.

Condensation can form under sarking that cools to the **outdoor** dew point in a ventilated roof space.

Insulation to avoid condensation under sarking may need protection from wetting by roof condensate.

Insulation on ceiling cuts heat loss but surface temperatures above become colder.

Colder roof spaces require better control of air leakage through ceilings.

Insulation in walls cuts heat loss but cavity temperatures become colder.

Colder sub-floor spaces can raise relative humidity and increase moisture levels in timber framing.

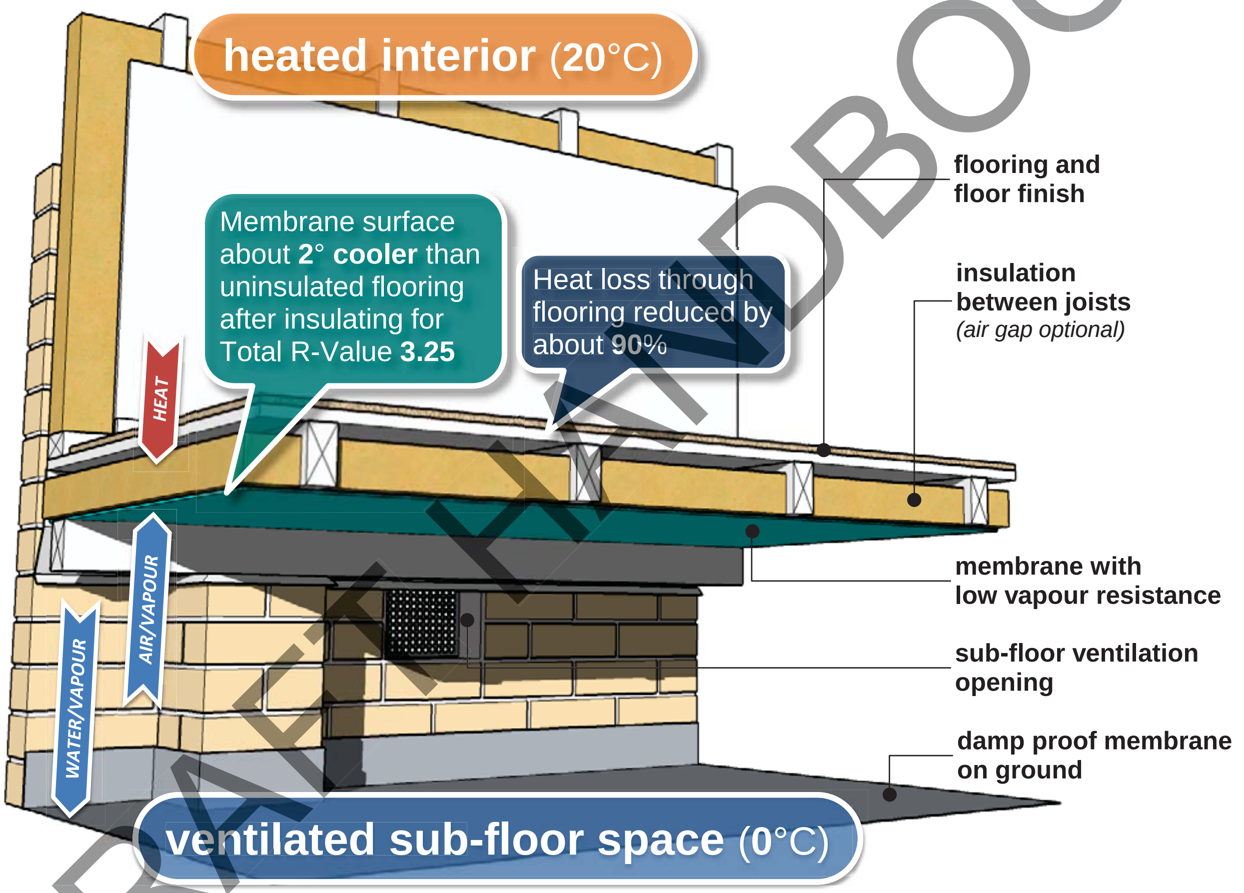
Colder sub-floor spaces may require membrane to seal ground surfaces.

Condensation can form inside impermeable wraps or panels that cool to the **indoor** dew point.

5.3 Higher Relative Humidity in Interstitial Spaces

Lower temperatures in interstitial spaces around an insulated interior are one of the expected effects noted in Figure 5.4. In cooler spaces, relative humidity 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 5.5 which illustrates an insulated timber floor intended for a cold climate.

Figure 5.5 – Suspended timber framed floor - insulated between joists (cold climate)



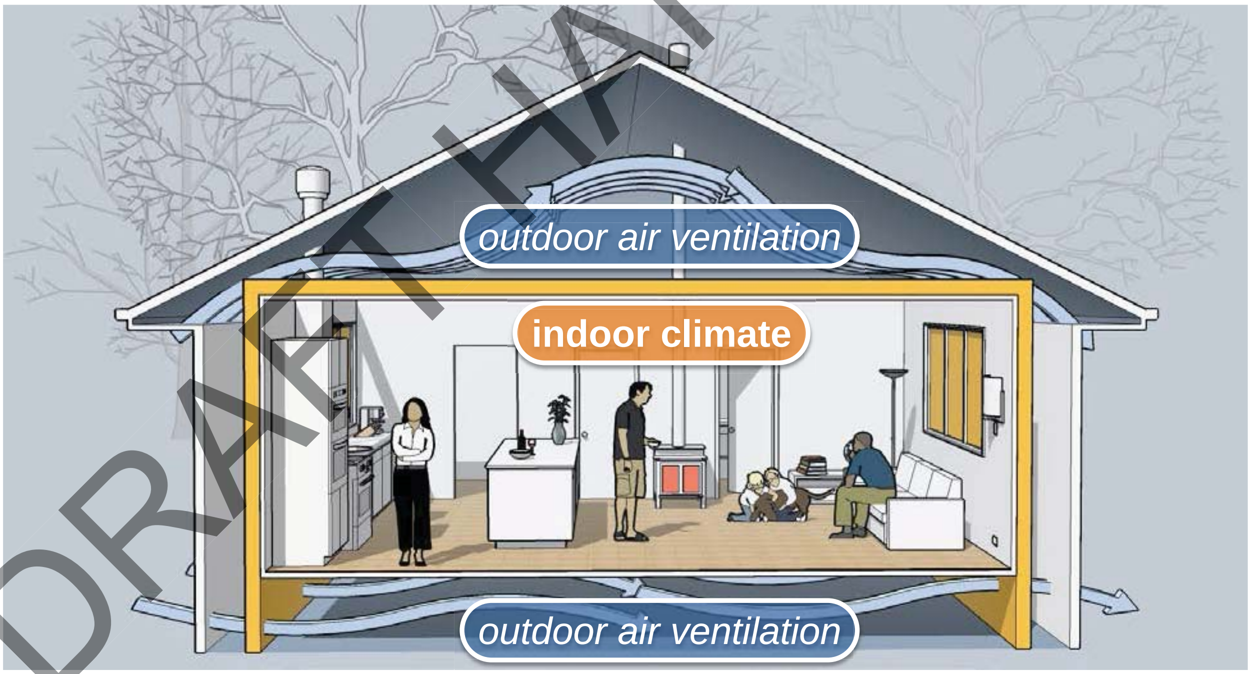
The suspended timber framed floor over a ventilated sub-floor space has insulation installed between the joists and supported on a membrane with low water resistance. This arrangement follows an example in British Standard 5250:2011 (Figure F.6). It does not attempt to retard water vapour migrating from the interior to the sub-floor space but relies on ventilation to keep the dew point in that space low and close to the outdoor level.

To assist the intended outward diffusion, the membrane under the joists must offer no more resistance to water vapour than the insulation it is supporting. Using a membrane that is also impermeable to air would limit any detrimental effect of the ventilating air stream on the insulation's thermal performance. Sealing the ground surface with a vapour impermeable membrane could help further to control water vapour levels and lower the dew point in the sub-floor space.

If this floor is insulated to achieve a Total R-Value of 3.25 in an alpine climate (as nominated in Table 3.12.1.4 in BCA Volume Two for climate zone 8), it would make the membrane surface under the insulation about two degrees cooler than the underside of uninsulated flooring in the conditions shown in Figure 5.5. It would also reduce the rate of heat loss through the flooring (if not the joists) by about 90%. The two degrees cooling could be enough to increase relative humidity from 60% to the 70% mould threshold at temperatures in which mould can be viable.

One way of dealing with risks of this nature is to keep moisture sensitive materials warm during the heating season by locating them inside the thermal control layer. In Figure 5.6, the thermal control layer (shown in yellow) for the occupied interior is extended to ground level to control heat loss through the perimeter of the sub-floor space. In practice, insulation would be applied to the interior faces of the enclosing walls. With little or no insulation under the flooring (at the designer's discretion), the timber framing can remain warm and dry.

Figure 5.6 – Suspended floor with insulated perimeter enclosure (applying BCA Clause 3.12.1.5)



NCC Alert

BCA Volume Two, Clause 3.12.1.5 allows the Total R-Value of an enclosed sub-floor assembly to be calculated taking account of the underfloor airspace and its enclosure. Some or all of any added insulation can then be applied to the enclosing walls of the sub-floor space. Use of that calculation method is not obligatory in 3.12.1.5 (and it is not offered in J1.6 of BCA Volume One).

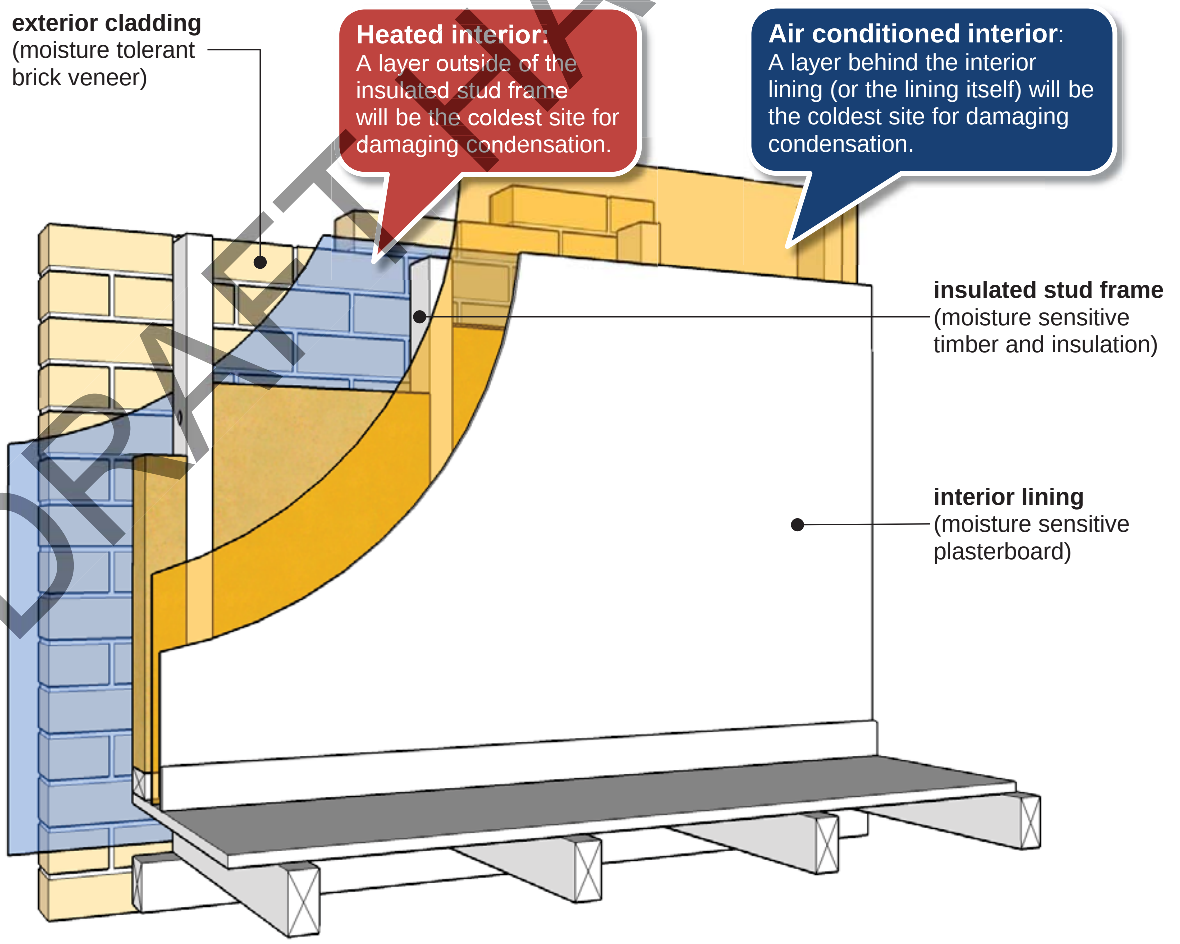
5.4 Condensation in Interstitial Spaces

Figure 5.4 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, its likely mobility and how long it persists. Assessing these questions in any details calls for analytical techniques of the sort outlined in Section 5.10.

When suitable assessment methods are not available or there is too little reliable information on climate and material properties to apply them, it seems prudent to apply reasonable means of keeping moisture sensitive materials out of harm's way. If the cost of attempting to do this, in the absence of confirmed risks, appears unreasonable, then competent detailed risk analysis will be unavoidable. Reasonable responses will, in general, aim to keep critical interstitial surfaces warm and the dew point of circulating water vapour low.

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 5.7 considers critical condensation surfaces in a brick veneer wall.

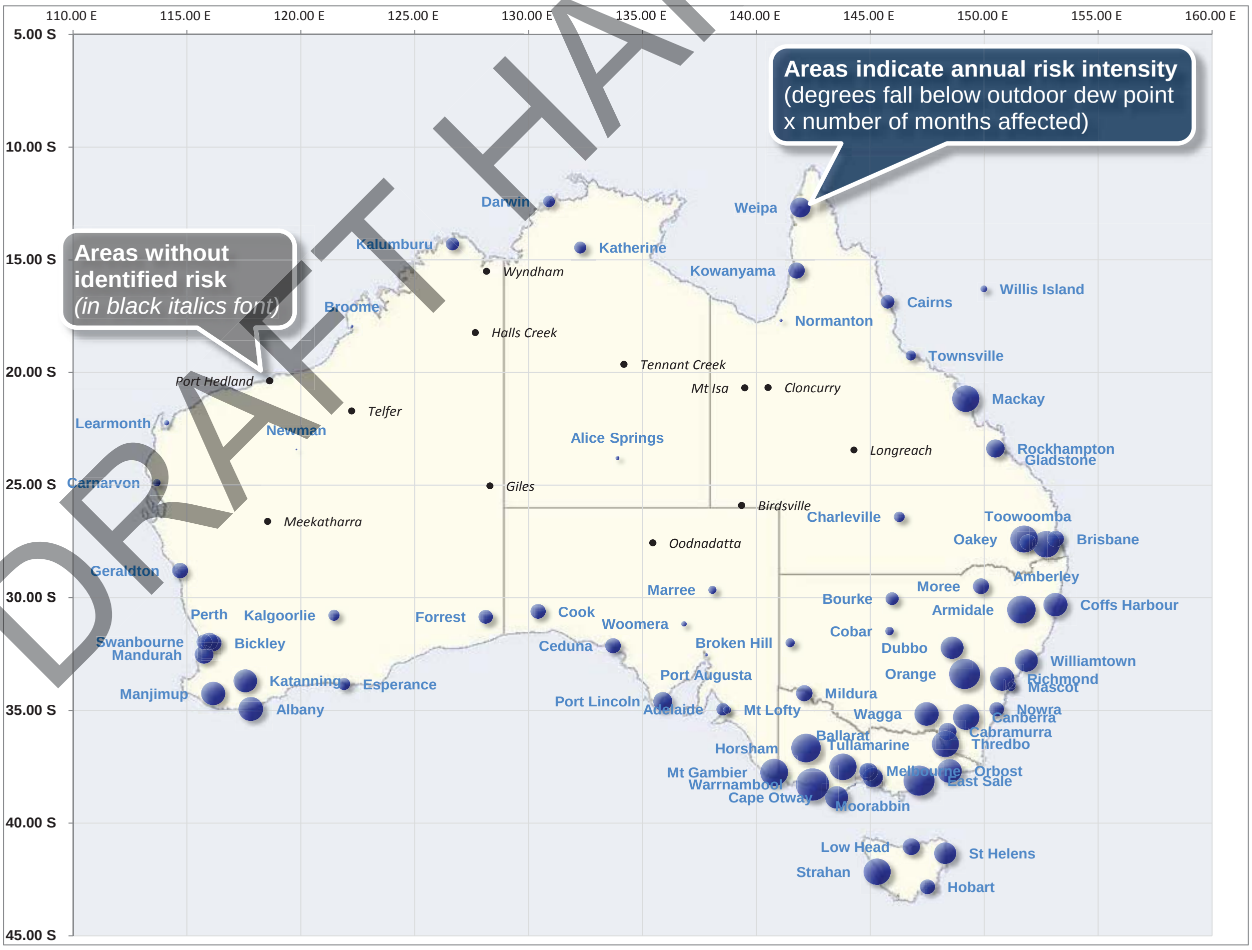
Figure 5.7 – Critical condensation surfaces in brick veneer envelope walls



Whether condensation does matter in a particular place will depend partly on the moisture sensitivity of the material it forms on and the materials it can affect by wicking, running, dripping or ponding. During winter, exterior brick veneer cladding, for example, will certainly be cold but any condensate forming there will be on a material designed specifically to deal with wetting. The two surfaces highlighted in Figure 5.7, however, often enclose timber framing and fibrous insulation. The timber 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 on the way.

It is not hard to find cold surfaces where condensation will matter in many Australian climates by considering overnight cooling to minimum temperatures. For roofs, the risk appears even greater when the effect of clear night sky cooling is also considered (Figure 5.8) even if the resulting condensate may not last beyond the next day. Overnight condensation is often so expected that it is routinely dealt with as part of the water control strategy that backs up the performance of the roof cladding.

Figure 5.8 – Roof cladding condensation potential with 2° of night sky cooling



Areas indicate annual risk intensity (degrees fall below outdoor dew point x number of months affected)

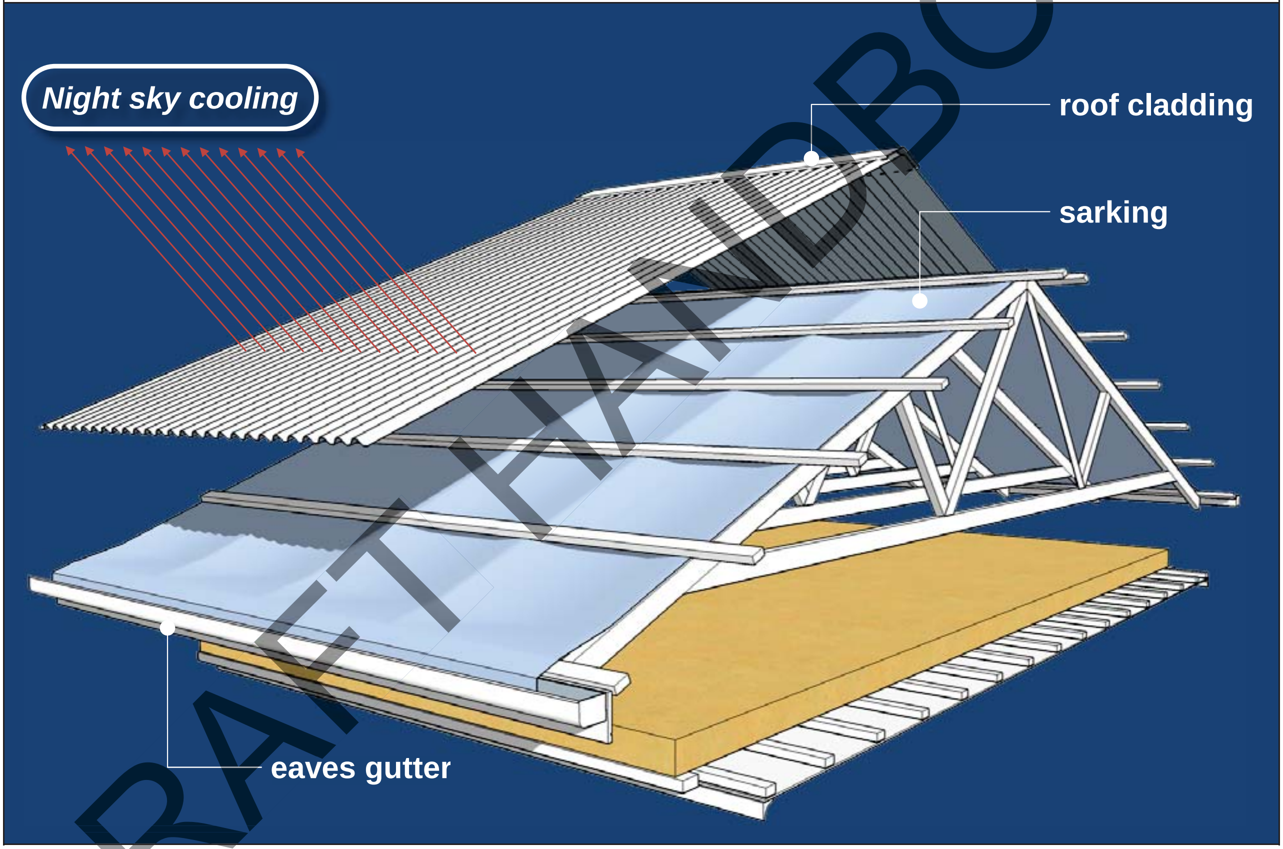
Areas without identified risk (*in black italics font*)

5.5 Water Control Layers and Drainage Planes in the Envelope

Roof cladding condensate

Although condensation under a metal deck roof can be avoided by using insulated roof cladding systems, it is usually accepted as being probable and is 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 5.9). This drainage plane mirrors, underneath the roof cladding, what happens to condensate deposited on top.

Figure 5.9 – Draining condensate formed on the underside of roof cladding



The condensation is caused by outdoor air circulating through roofing corrugations or ribs which respond rapidly to falling temperatures overnight and may cool further, to several degrees below the outdoor air temperature, by radiating heat to a clear night sky. This type of condensation can happen in many locations on many nights of the year. 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 4.3 and the map in Appendix A.1). A review of climate data for 160 Australian locations shows that roof cladding condensation can occur in 95 of them 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.

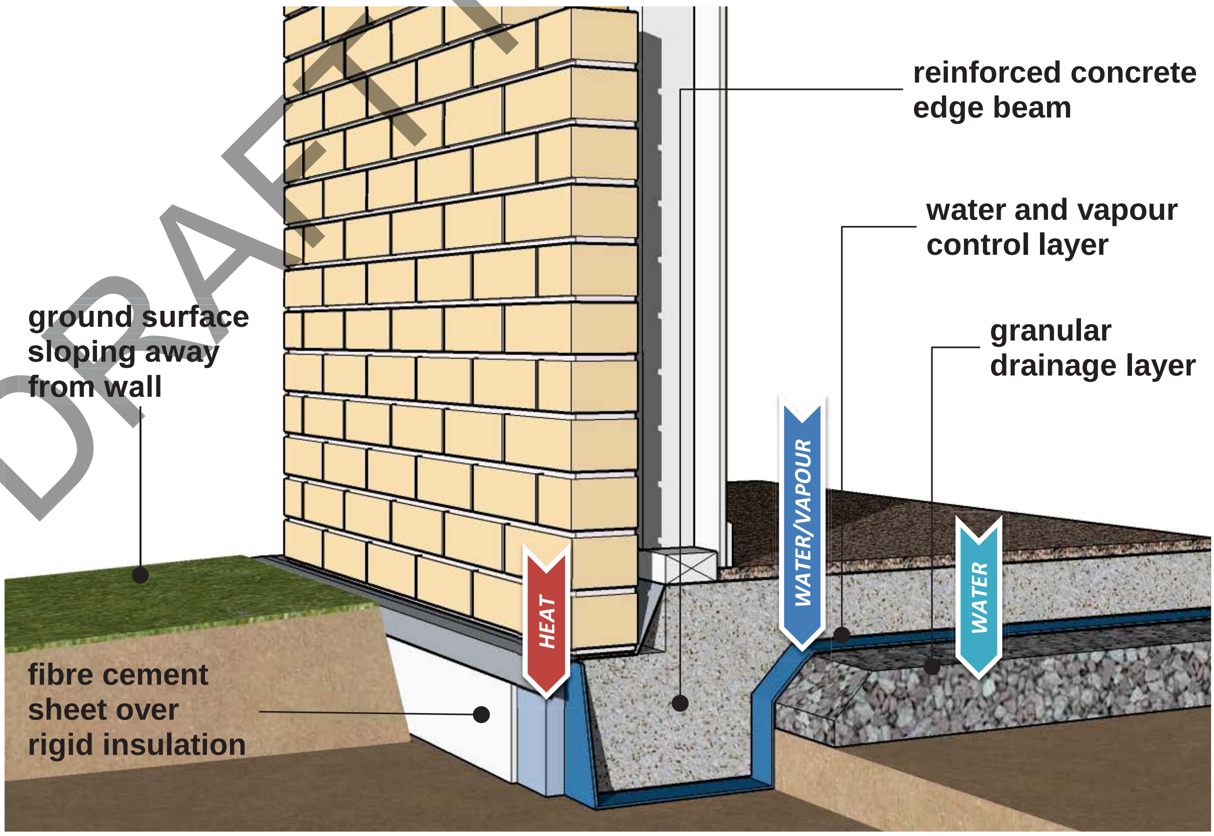
The sarking membrane in this roof serves as a water control layer (or drainage plane) to dispose of condensate which could otherwise drip onto any ceiling or insulation below. It must be waterproof but need not necessarily offer a high resistance to water vapour. Some capacity to absorb and temporarily detain water could also be an advantage when condensate levels are likely to be high.

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 is still 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.

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 5.10).

Figure 5.10 – Slab on ground floor water control arrangements



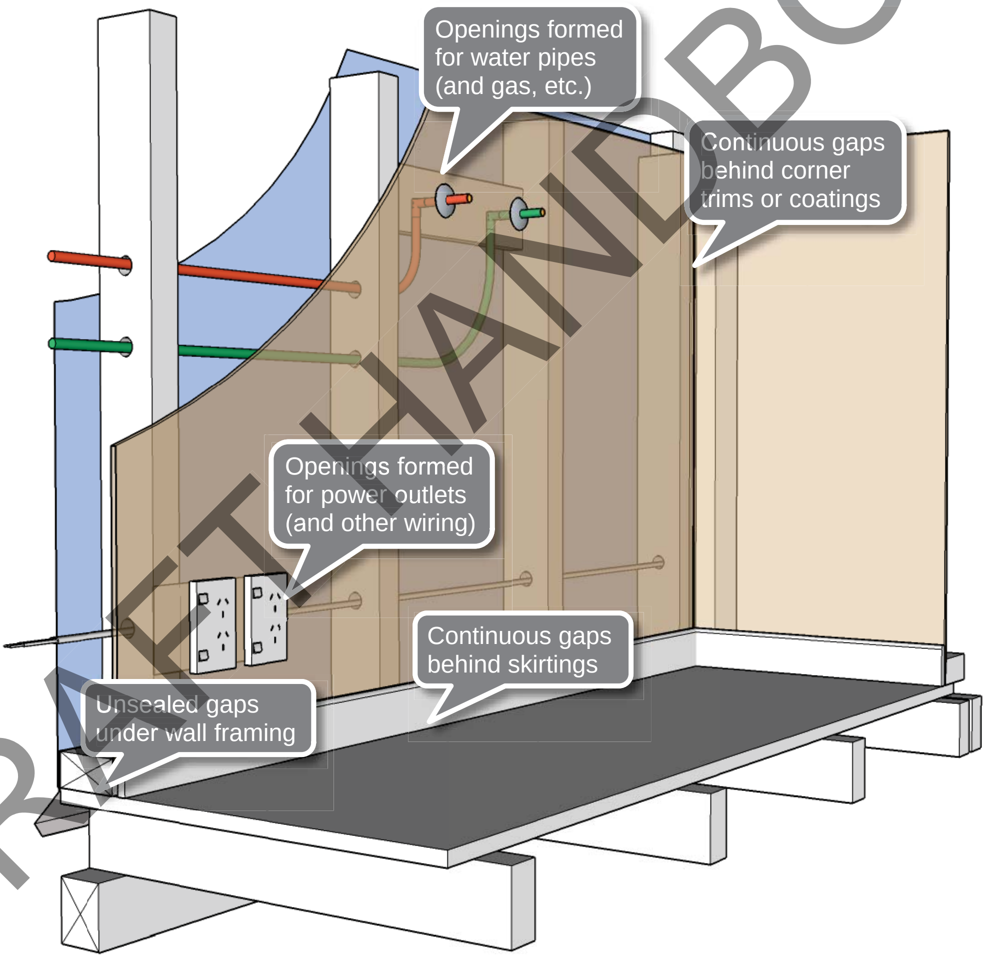
To minimise water and vapour pressure under the slab and to create a capillary break, a 100 mm granular drainage bed should be formed using coarse aggregate (with no fines). The bed should discharge collected water clear of the building base and be vented to the atmosphere to assist drying.

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 to ensure the insulation remains undamaged from the outset.

5.6 Air Control Layers

Looking at the wall and ceiling linings of any domestic interior might suggest that air leakage across the building envelope is well under control. The appearance is often deceptive. 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 5.11). The cumulative effect of such leaks is easily overlooked because of familiarity and the seeming lack of ready alternatives for accommodating services.

Figure 5.11 – Some typical air and water vapour leakage sites through internal wall linings

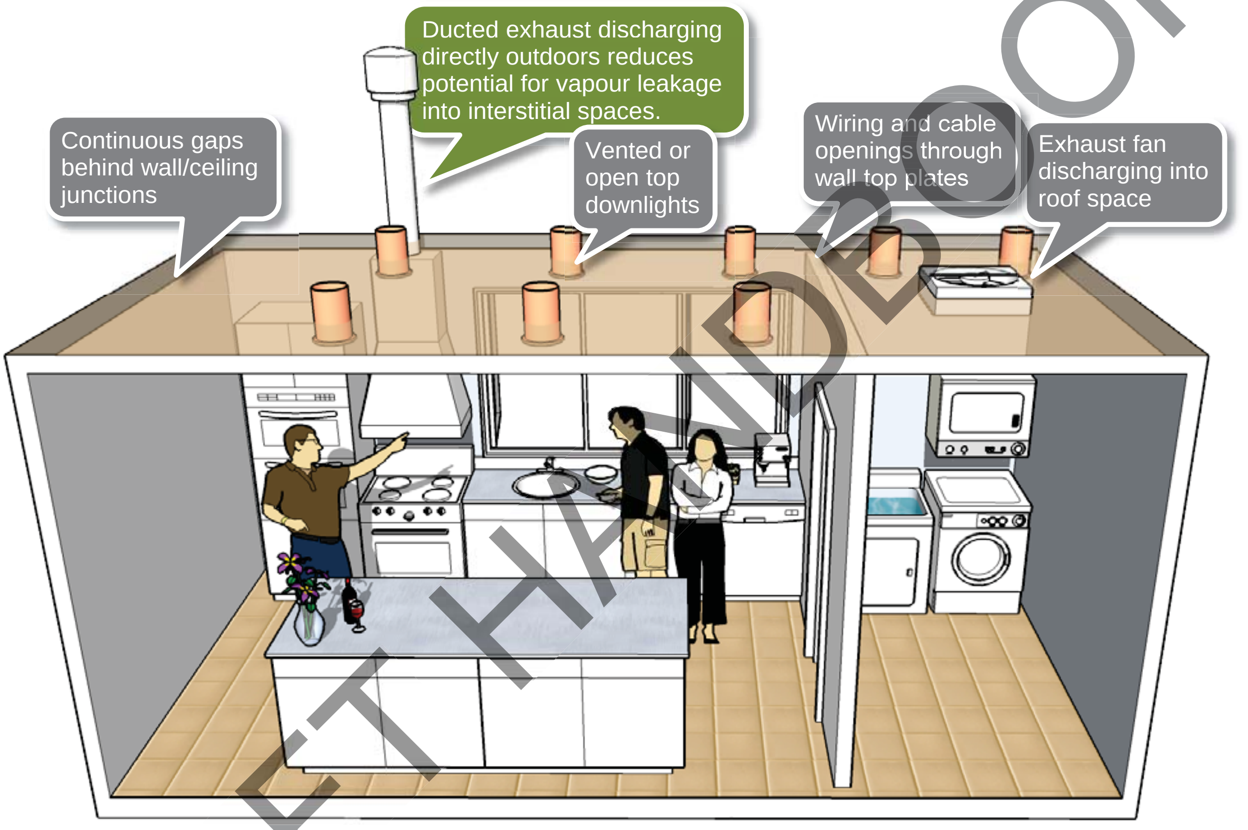


NCC Alert

The NCC DTS Provisions for sealing of roofs, walls and floors in J3.6 of Volume One and 3.12.3.5 of Volume Two do not mention openings for services as sites for air leakage and require only that linings are "close fitting at ceiling, wall and floor junctions". Sealing by "caulking, skirting, architraves, cornices or the like" is listed as an alternative to "close fitting".

At ceiling level, other shortcuts for air and water vapour movement are often available (Figure 5.12). Unsealed downlights, in particular, can short circuit insulation and whatever control the ceiling construction might offer against unwanted leakage of air and water vapour into (or from) the roof space above.

Figure 5.12 – Some air and water vapour leakage sites through ceilings



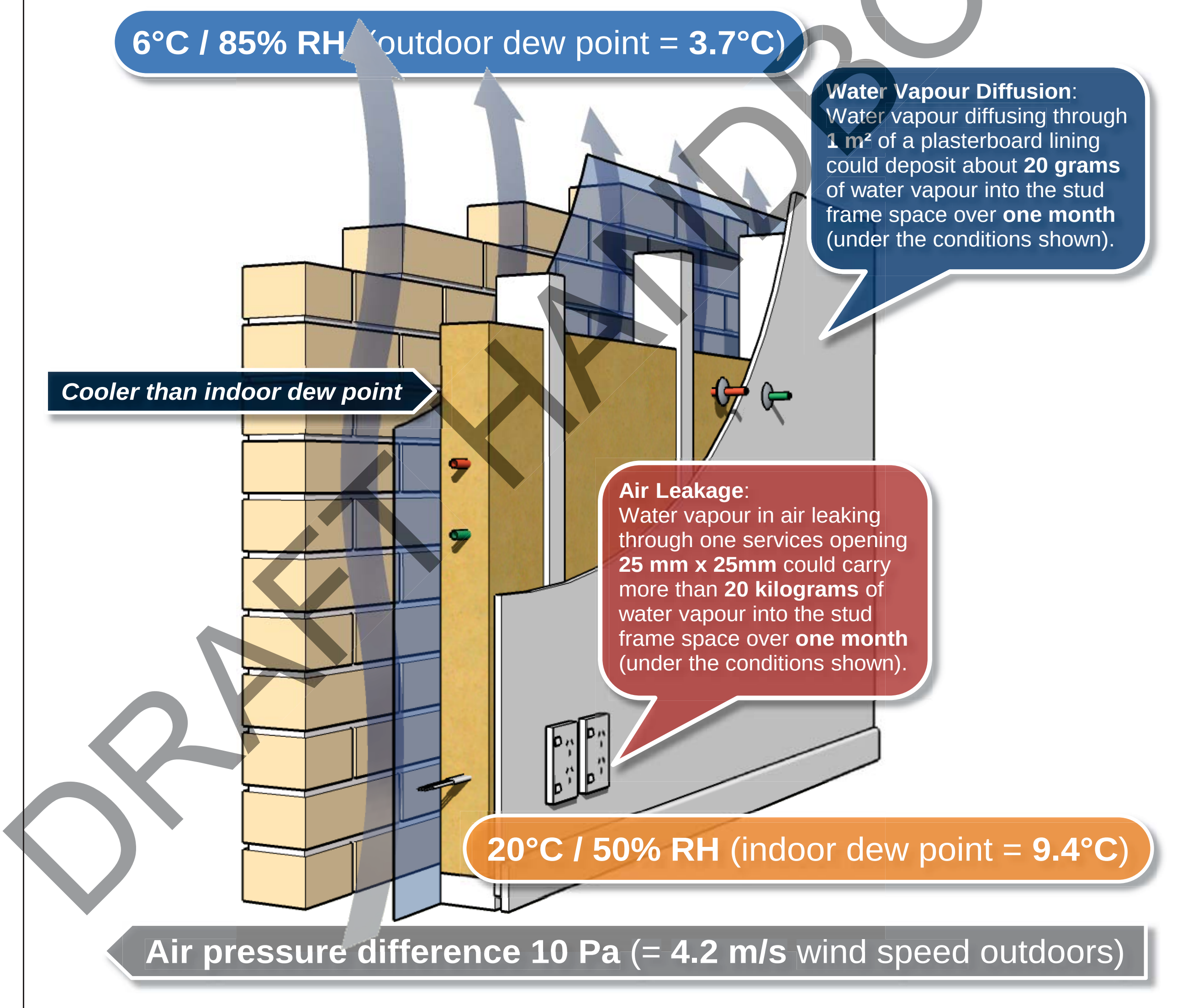
NCC Alert

The NCC energy efficiency provisions in J3.5 and 3.12.3.4 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. Explanatory information for 3.12.3.4 suggests that a typical filter is adequate for sealing a range hood. 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 to sealing.

Similarly, 3.8.5.2(c) in BCA Volume Two allows an exhaust fan to discharge into a roof space that “is adequately ventilated by open eaves and/or roof vents; or is covered by roof tiles without sarking”. Where there is potential for condensation, better practice would be to discharge the fan directly outdoors. For downlights and other openings through ceilings, the extra insulation requirements of J1.3(c) and 3.12.1.2(e) address only thermal effects and are not expected to mitigate condensation risks from leakage of water vapour into the roof space.

When attempting to control the movement of water vapour through interstitial spaces, the leakage of air with high water vapour content can disrupt a well-intentioned vapour control strategy. Figure 5.13 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. Water vapour entering the stud frame space of the wall will contact the membrane on the exterior face, which was identified in Figure 5.7 as a possible condensation site during the heating season by having a surface temperature below the dew point of water vapour in the indoor air.

Figure 5.13 – Comparison of water vapour transport by diffusion and by air leakage



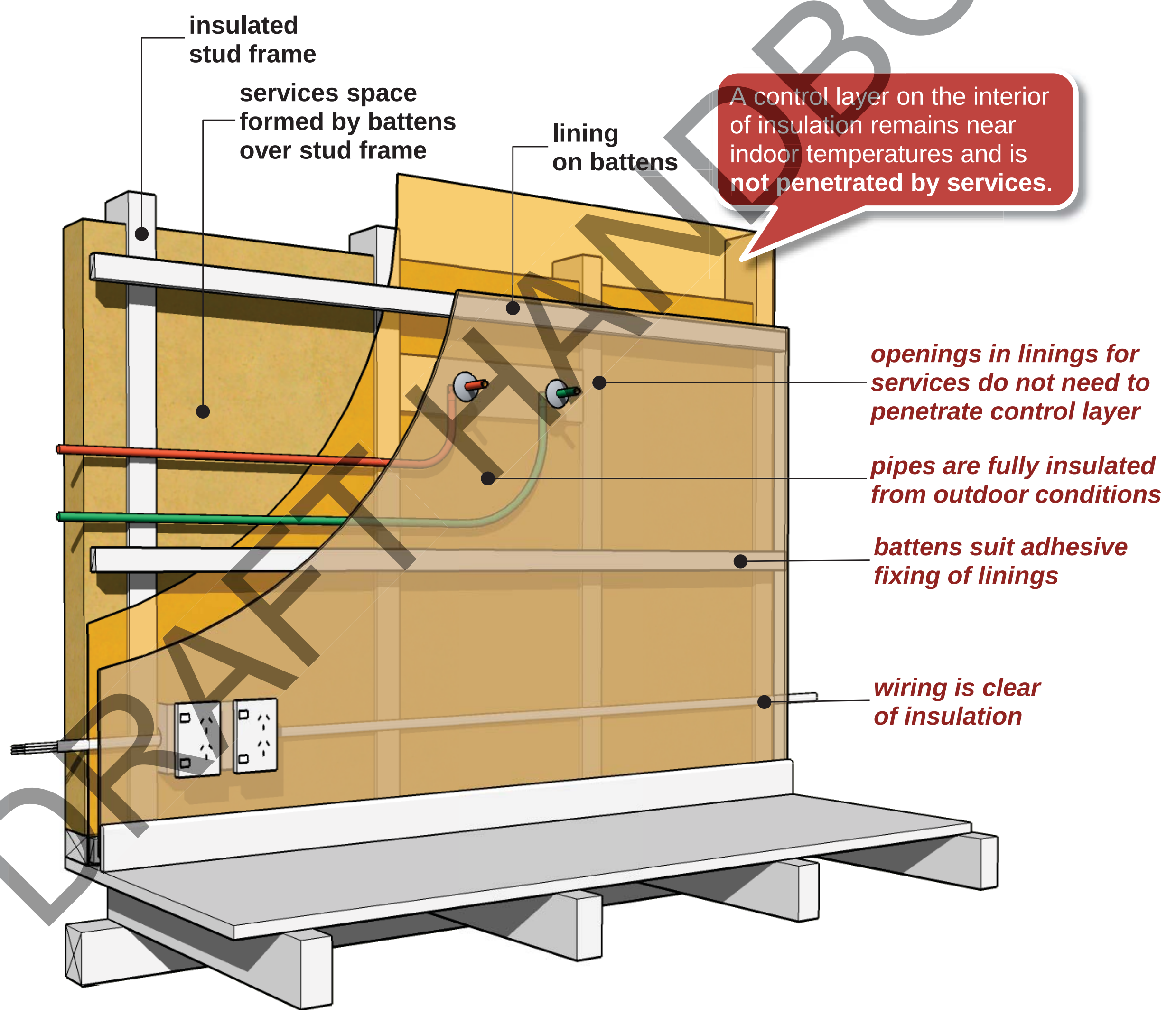
Water Vapour Diffusion: Water vapour diffusing through **1 m²** of a plasterboard lining could deposit about **20 grams** of water vapour into the stud frame space over **one month** (under the conditions shown).

Air Leakage: Water vapour in air leaking through one services opening **25 mm x 25mm** could carry more than **20 kilograms** of water vapour into the stud frame space over **one month** (under the conditions shown).

Not all of the water vapour carried by air leakage will remain in the stud frame space. In the nature of leaks, which need inlets and outlets, much of the flow may find relatively direct pathways to the outside. The heat in the air and water vapour can warm these paths enough to keep them above the dew point of the leaking 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).

If the conditions illustrated in Figure 5.13 persisted for a month, a single services opening 25 mm x 25 mm could transmit more water vapour at risk of condensing than 50-100 m² of the interior wall surface of the envelope. Given this, it might seem a significant limitation for current condensation risk assessment methods and software (Section 5.9) to focus on diffusion rather than air leakage as the likely source of condensation.

Figure 5.14 – Battened services space to avoid penetration of control layers in envelope walls



Emphasising the importance of effective air control, British Standard BS 5250:2011, 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 5.14. The material selected for the air control function and its installation would need to produce an airtight surface but its resistance to water vapour transmission would depend on the vapour control strategy developed in response to the issues discussed in Section 5.7.

This removes practical obstacles to installing an effective vapour control layer on the interior side of insulation but a high resistance material would be appropriate only in cold climates (and may not be necessary, even there). This is not a suitable location for a highly impermeable material in a tropical climate or in a climate which will encourage air conditioning use in summer. Depending on the permeance of other layers closer to the exterior, extra water vapour resistance might be beneficial in cool temperate climates.

5.7 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.

Cold climate vapour barriers were extensively adopted in warmer climates across the United States during the 1990s as the answer to winter season condensation. The polyethylene membranes installed as vapour barriers behind interior linings were soon revealed as sites of condensation during summertime air conditioning. Reflecting on this experience, in Errata to his Moisture Control Handbook, in June 2002, Joseph Lstiburek observed:

> *"In the past decade several things have become obvious to me that are not reflected adequately in the Handbook. The most significant is the role of polyethylene on retarding the drying of building assemblies. I have come to conclude that polyethylene is really a 'drying retarder' and should be avoided. Polyethylene should not be installed on the interior of any assembly – with the exception of above grade walls and ceilings in locations with 8,000 heating degree days or greater."*

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 in dwellings (with 0.7 air conditioners per household when assessed in 2006) 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 prolific 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 (such as vinyl wall coverings) to the envelope of air conditioned buildings.
- Ventilate building interiors to achieve an acceptable specific hourly air change rate. (Lstiburek refers to ASHRAE Standard 62.2 for low rise residential buildings or ASHRAE Standard 62.1 for commercial buildings)

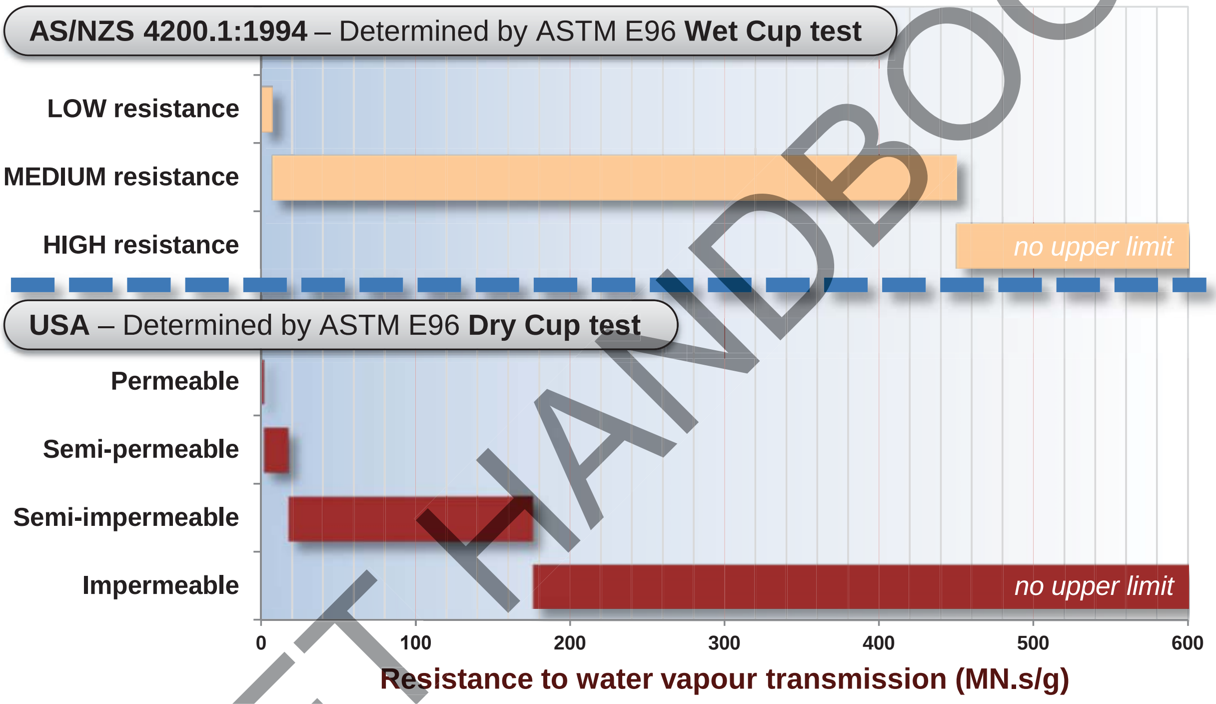
NCC Alert

In the Deemed-to-Satisfy Provisions of BCA Volume Two, Clause 3.8.5.0 nominates AS 1668.2 – Mechanical ventilation for acceptable indoor air quality as an Acceptable Construction Manual for a mechanical ventilation system. In addition, Clause 3.8.5.2 describes the Acceptable Construction Practice for natural ventilation in terms of opening sizes.

BCA Volume One has similar provisions in Part F4.6 for natural ventilation but Part F4.5 requires a mechanical ventilation or air conditioning system to comply with AS 1668.2 and AS/NZS 3666.1.

Some clarification of terms is needed. 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. Figure 5.15 compares the performance categories used in Australia and in North America.

Figure 5.15 – Comparison of Australian and North American categories of water vapour resistance/permeance

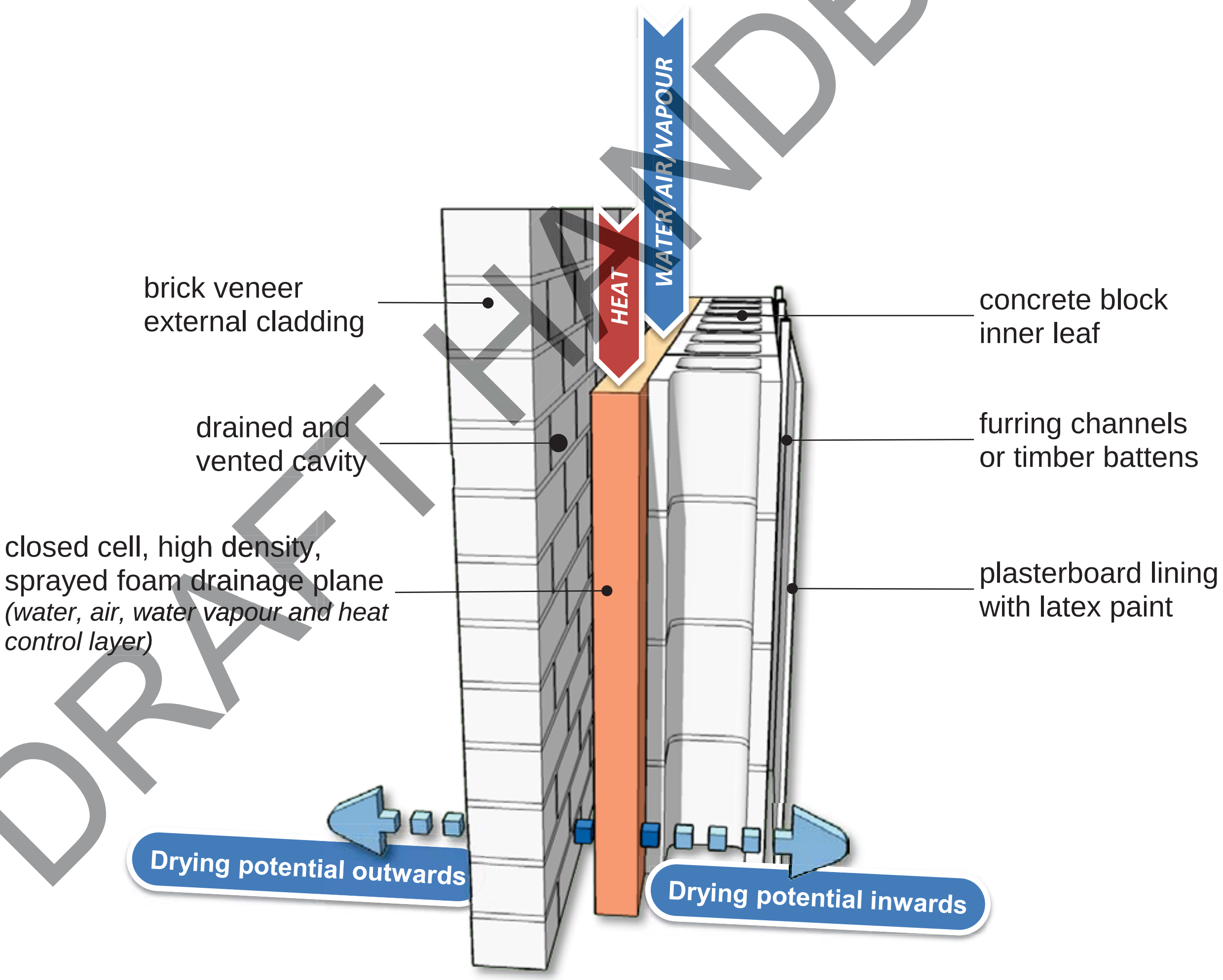


To illustrate the application of his moisture management principles, Lstiburek also offers specific examples of assemblies for roofs, walls and floors which have been demonstrated by laboratory testing, computer simulation and experience to provide satisfactory performance in all or many of the United States climate regions mentioned in Section 4.2 (Lstiburek 2010 and 2011b). Two cases are illustrated in Figure 5.16 and Figure 5.17 to show Lstiburek's implementation of his 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.

Water Vapour Control in Walls

Figure 5.16 – Joseph Lstiburek's 'Clever Wall' - using a single material for four control functions

(Source: Lstiburek 2010, Figure 7)

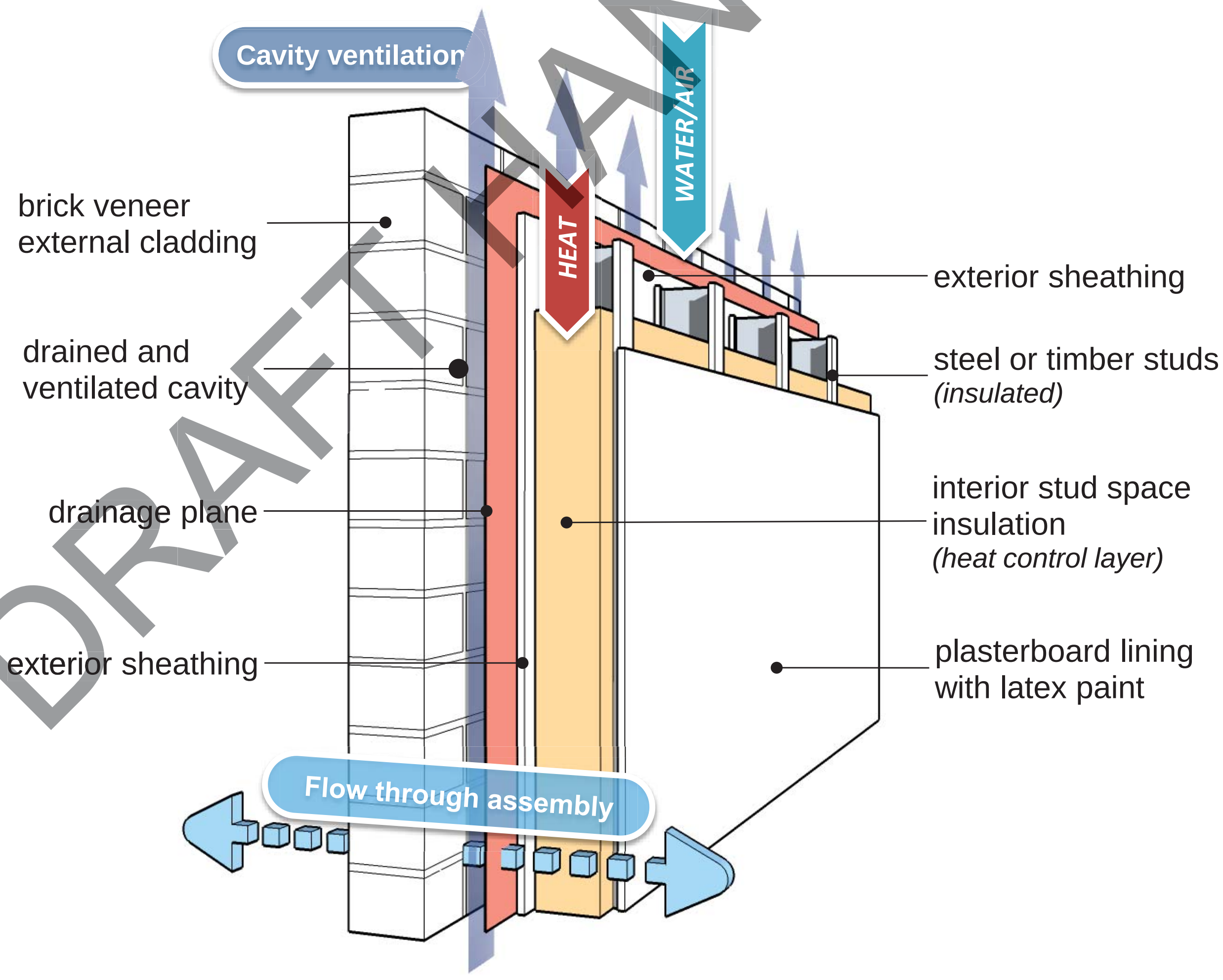


The wall in Figure 5.16 shares the brick veneer and concrete block construction of a wall that Lstiburek (elsewhere) dubs the "institutional wall" and considers to be "the best wall we know how to construct". The "clever wall" differs from the "institutional wall" only by using a single material to achieve all four principal control functions A closed cell, high density foam (32 kg/m³), spray applied to the concrete block leaf, serves to control the movement of water, air, water vapour and heat across the assembly. The resulting wall can operate successfully in any of the eight US climate regions (illustrated in Figure 4.5), adjusting only the level of thermal insulation to suit the location.

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.

By contrast, the residential wall in Figure 5.17 relies on being able to dry in both directions.

Figure 5.17 – Insulated stud frame wall with brick veneer cladding
(Source: Lstiburek 2011b, Figure 6)



The wall assembly in Figure 5.17 shares many of its elements with Australian brick veneer domestic construction. Lstiburek suggests it can be used in US climate regions 1 to 4 but not in colder locations. Its performance and its climatic limitations result from its “flow through” or “vapour open” construction which can dry towards both the interior and the exterior.

To achieve that, 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.

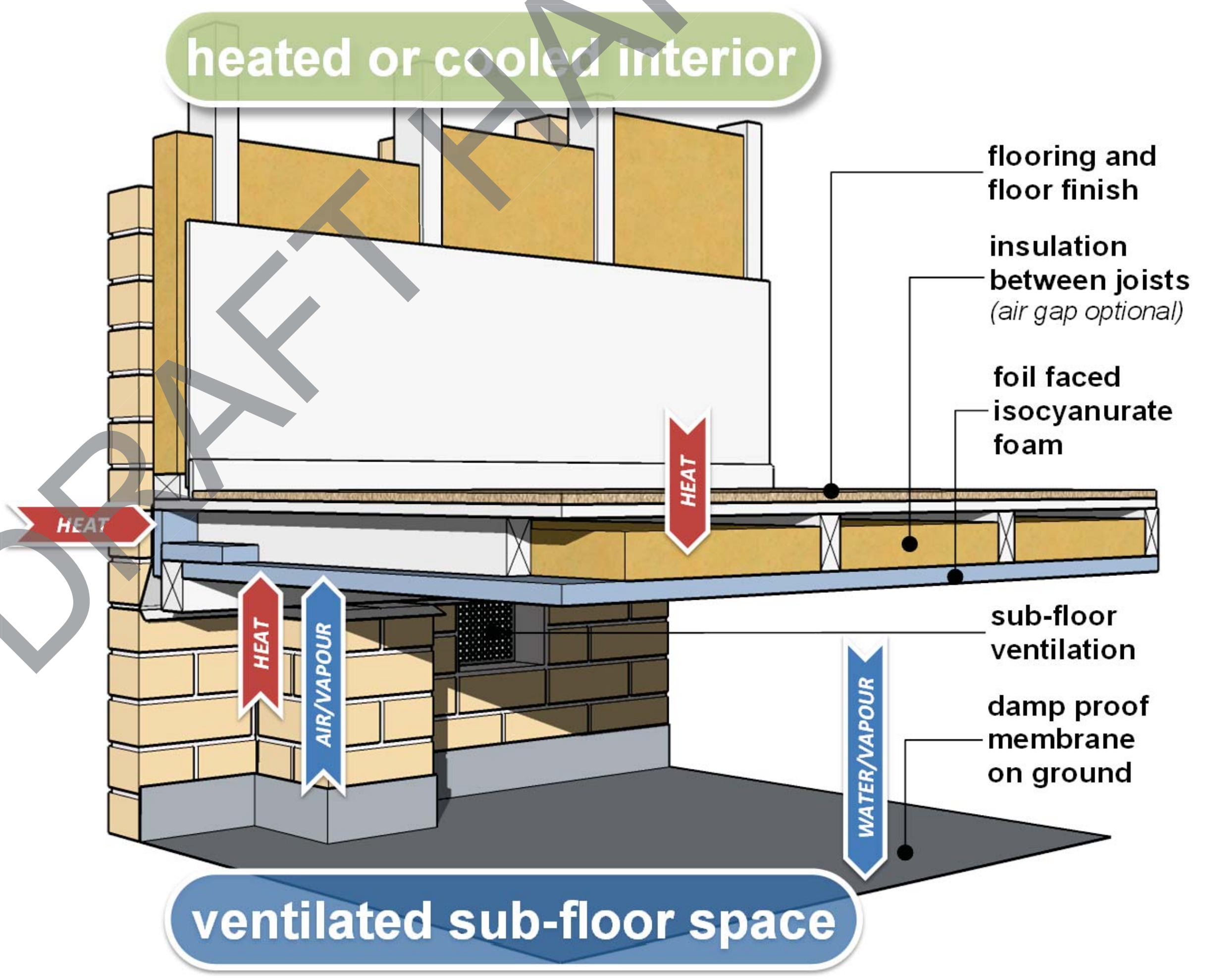
The wall differs from Australian practice by having full sheathing applied to the exterior face of the stud frame. Plywood or oriented strand board (OSB) sheathing is common for framed construction in North America and Europe but unusual in Australia. The absence of such sheathing here would reduce the moisture storage capacity of the assembly and require caution about adopting it in condensation prone climates and cooler climates.

Water Vapour Control under Floors

The suspended timber floor shown in Figure 5.5 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 United States, 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 relative humidity 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 5.18) 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. An alternative would be to encase the floor framing and underside of flooring in high density sprayed foam (minimum 32kg/m^3) at least 75 mm thick.

Figure 5.18 – Suspended timber framed floor with summertime risk of inward vapour drive



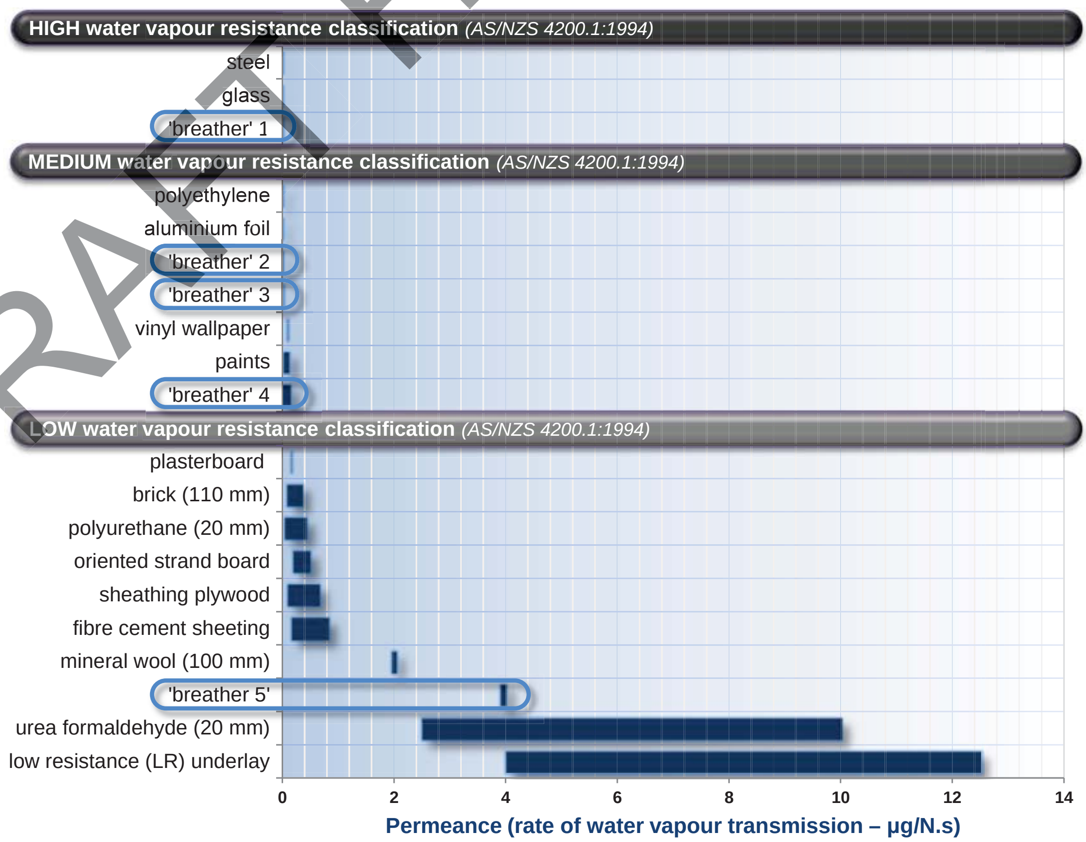
Vapour Permeable Materials

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. The confusion could start with the two terms but they are simply measures of how ready or reluctant a particular material is to allow the passage of water vapour. A performance value for one is the reciprocal of the other.

AS/NZS 4200.1:1994 identifies three classifications of water vapour barriers, ranked High, Medium or Low according to their resistance. Low resistance under AS/NZS 4200.1:1994, however, does not necessarily mean high permeance because of the range of resistances accepted as Low.

Some products are marketed as “breather” membranes, implying high permeability, but might not state performance values for either vapour resistance or vapour permeance. Figure 5.19 shows permeance values for a range of building materials and membranes, grouped within the resistance classifications of AS/NZS 4200.1:1994. Comparing the performance of the “breather” membranes suggests the possibility of unexpected outcomes if materials critical to an intended water vapour control strategy are specified or supplied on the basis of generic labels rather than specific performance requirements.

Figure 5.19 – Water vapour permeance of some building materials and permeable membranes

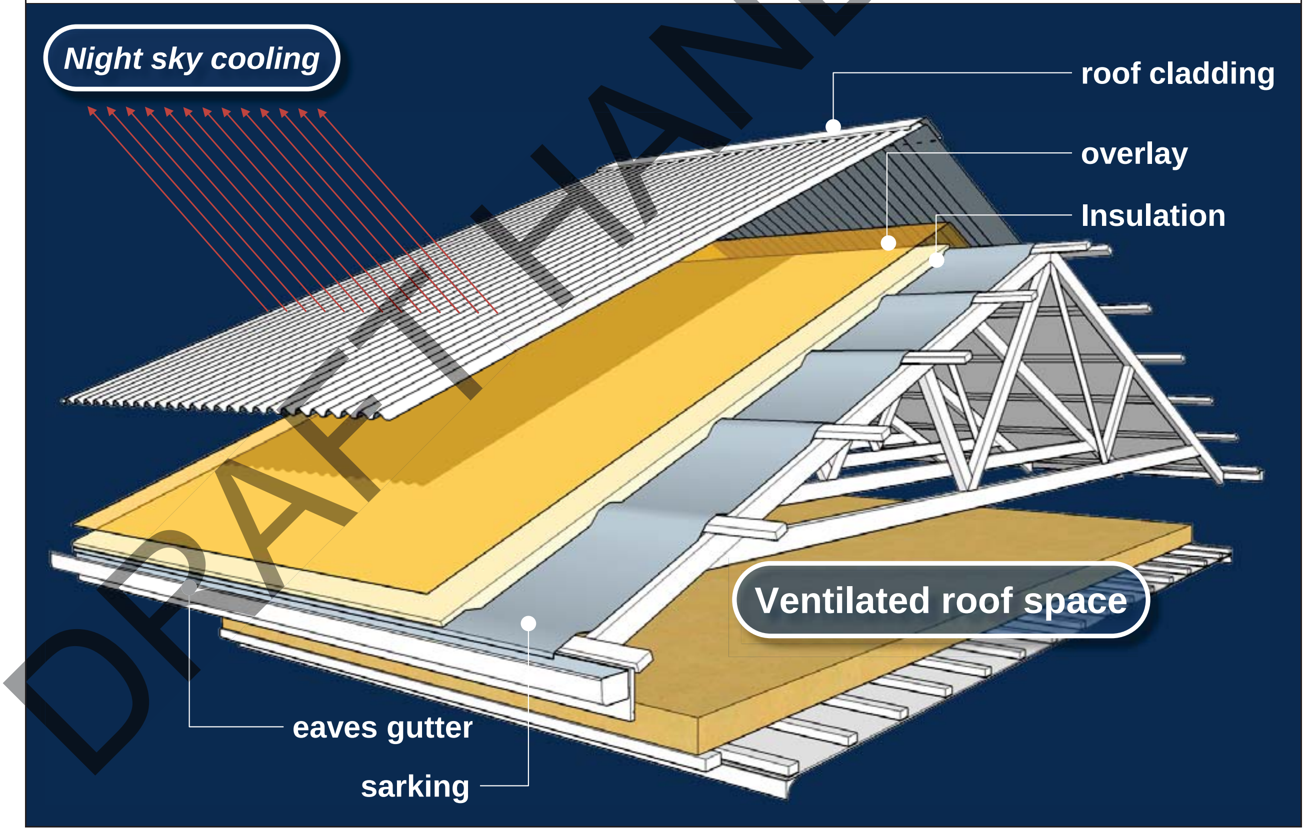


5.8 Thermal Control Layers

Where any material forms a substantial barrier to the movement of water vapour, intentionally or by oversight, it needs to be kept warmer than the dew point of any water vapour able to reach it and condense in problematical amounts. Where condensation risks are due to falling temperatures outdoors, the critical dew point will most often result from indoor water vapour levels. Where the risk is due to cooling indoors, the critical dew point will depend on outdoor water vapour levels.

To illustrate the notion of managing the temperatures of likely condensing surfaces, Figure 5.20 shows a roof space relying on outdoor air to dissipate indoor water vapour leaking or diffusing through the insulated ceiling below. (In this sense, the roof is like the floor assembly in Figure 5.5, turned upside down.) If the ventilation is effective, the dew point in the roof space will remain close to the average outdoor dew point.

Figure 5.20 – Minimising condensation on the underside of sarking - sarking as temperature control



In some locations, the overnight temperature can fall below the outdoor dew point and trigger condensation due only to outdoor conditions. Section 4.3 discusses how to identify whether a particular climate might be affected. For those locations, condensation of this sort will be inevitable from time to time and the underside of the sarking will be the most likely site for it. When the triggering temperature for condensation is delivered by the ventilating air itself there is little to be done but to consider how to detain the condensate where it forms to avoid damage elsewhere until drying conditions return.

Condensation will be more likely if night sky cooling (discussed in Section 5.5) can take the sarking surface temperature below the outdoor air temperature. An indicator of this risk would be to compare the outdoor dew point temperature with the minimum air temperature, reduced by an allowance for night sky cooling. Where condensation seems possible, the sarking will need enough thermal resistance to keep its surface close to the roof space temperature.

The sarking may have some intrinsic thermal resistance and draping it between framing members to form the drainage channels shown in Figure 5.20 can provide more. If bulk insulation is added above the sarking, it will need to be insensitive to moisture or be protected from roof cladding condensate by an overlaid membrane which is waterproof but highly permeable to water vapour. This will allow moisture entering the insulation layer to migrate through the overlay into the ventilated space between corrugations or ribs in the roof cladding.

5.9 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.

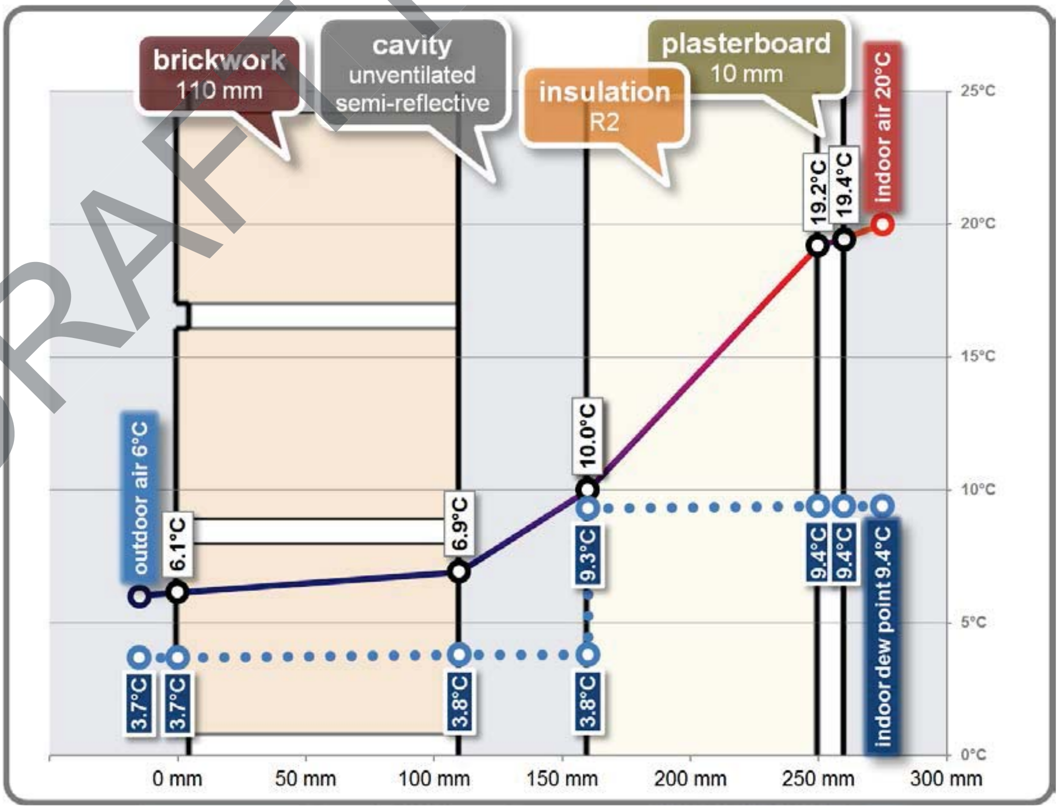
Steady state methods

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 5.21).

Figure 5.21 – Steady state comparison of temperature and dew point gradients across a wall



The most widely used steady state approach bears the name of Glaser, who first presented work on the method in German publications in 1958 and 1959. In America, Rowley is credited with the creation of vapour diffusion theory and the “profile method” of analysis in the late 1930s. Glaser developed his approach for controlling condensation in the walls of cold stores. For this purpose, the method provided reliable results because the construction involved was airtight with few porous materials and the temperature and water vapour conditions were, in reality, close to steady state. With water vapour diffusion as the main vehicle for moisture movement across the assembly, calculation of condensation and evaporation in the assembly to establish an annual moisture balance was relatively straightforward. Current applications of the Glaser method have moved a long way beyond that specialised context.

The Glaser method forms the basis of ISO Standard 13788:2012, which has been adopted as a British, European and International Standard. The introduction to ISO 13788:2012 (outlined in Section 6.6) advises that the standard gives simplified calculation methods for moisture transport by diffusion alone, using monthly average climate data. The calculation methods deal with internal surface condensation, interstitial condensation and estimated drying times for wet components.

The introduction also notes that the standard does not cover the effects of ground water or precipitation or address the issue of “airflow from the interior of the building into the structure”. It goes on to suggest that the standard’s limitations mean that “it can provide a more robust analysis of some structures than others. The results 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.”

The requirements of ISO 13788:2012 have been embodied in commercially available software packages and development is well advanced on at least one version intended for use under Australian conditions with local climate and materials data.

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 Glaser method considers only the conduction of heat and the diffusion of water vapour, transient methods aim to account for 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) under conditions which are realistic for the indoor and outdoor climates and the initial state of the building fabric.

These ambitions mean that 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.

British Standard BS EN 15026:2007 (outlined in Section 6.6) defines the practical application of one-dimensional transient calculation methods and their essential inputs and outputs. Those outputs predict conditions in the building fabric but do not deal directly with matters of energy use, mould growth, decay, corrosion or other forms of moisture damage. Additional post processing tools are needed to explore such issues.

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.

A prominent example of numerical simulation software complying with BS EN 15026:2007 is the German developed WUFI (Waerme und Feuchte Instationaer, or transient heat and moisture). The model has been under active development by the Fraunhofer Institute for Building Physics (IBP) since the 1990s and is considered one of the most advanced of the commercially available programs. Its output has been validated against full scale field tests over many years (Straube and Schuhmacher, 2006). Other validated programs exist and a range of more advanced non-commercial programs are also used for research purposes.

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. Although the Introduction to BS EN 15026:2007 suggests that transient models can take account of “liquid and convective transport”, convection is not listed as one of the moisture transport phenomena in the document’s statement of Scope. A later caution advises that “the hygrothermal equations described in this standard shall not be applied in cases where: convection takes place through holes and cracks”.

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.

5.10 Design Checklist

Climate Analysis

- Understand the outdoor climate that acts on the building. As a first step, use the map in Appendix A.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 4.3). 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 4.4, using BOM data and the basic psychrometric chart in Appendix A.3. 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 4.6 allows a basic assessment of the impact of the indoor climate on likely interstitial condensation risk. If there are any indications of problems (or close approaches to them) 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 on 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.

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 well enough (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.

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 air spaces.

Communicating the Condensation Control Strategy

- Convey intent of moisture control strategy to the builder and follow its implementation through construction.
- Document the implemented strategy, including any changes needed during construction and convey its essential elements to users.
- Make moisture management easier for users (by providing extraction at source wherever possible and building in trickle ventilation).

5.11 Construction Checklist

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 detailing which are intended to avoid both interior surface condensation and interstitial condensation. For surface condensation, the advice might mention avoiding thermal bridges across framing members which can cause local cooling of the interior linings. For interstitial condensation, the emphasis might be on minimising air leakage and the installation of membranes or sheet materials with specified 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 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. 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 high resistance to water vapour transmission. Materials with a lower resistance should not be used without the designer's agreement. In a hot climate, these materials will usually be installed on the warmer exterior side of any insulation and, in a cold climate, on the warmer interior side. The intended location should be verified specifically with the designer in each case.

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 openings 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 intended to encourage the passage of water vapour, for example, are often marketed as 'breather' membranes. Figure 5.19 highlights differences in product performance which shows 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, 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.

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.

5.12 Occupancy Checklist

- The comments and suggestions here apply mainly to dwellings 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 4.9 (and enlarged in Appendix A.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 relative humidity or condensation indoors. In most cases, those problems can be avoided by simple choices householders can make in day to day activities, as suggested in the list below:
- 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 relative humidity that can support dust mite infestations and mould growth (Section 3.6). 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 relative humidity 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 relative humidity and to minimise the risk of condensation, in a building showing signs of problems, notice which activities release water vapour indoors (Section 4.5) 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 relative humidity. 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 relative humidity 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% relative humidity 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 relative humidity in a dwelling.
- Although generalised heating has a beneficial effect in lowering relative humidity (Section 3.5), 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 make 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 dwelling 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) relative humidity to fall.
- Seek informed advice when selecting an air conditioning unit or 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 about 80 times greater than in Melbourne.

6 Codes and Standards

6.1 Building Control

Each Australian State and Territory is responsible for building control in its own jurisdiction. Legislation in each State or Territory adopts the NCC as the technical standard for the design and construction of buildings, subject to variation or deletion of some of its provisions or the inclusion of additional provisions. Those amendments are contained in Appendices to the NCC.

The NCC has legal effect only through regulatory legislation in each State and Territory which also contains the necessary administrative provisions. Those arrangements generally apply the NCC to new buildings, new work in existing buildings and changes in building use or classification. Since any of its provisions may be affected by State or Territory legislation, the NCC should be read in conjunction with that legislation. Advice on interpretation in a particular jurisdiction should be sought from the responsible authority.

6.2 The NCC Series

The NCC is an initiative of the Council of Australian Governments, developed to incorporate all on-site construction requirements into a single code. It is published in three volumes, with Volumes One and Two forming the Building Code of Australia (BCA). The BCA provides a uniform set of technical provisions for the design and construction of buildings and other structures throughout Australia. Volume Three of the NCC is the Plumbing Code of Australia.

All three volumes present a performance-based approach which allows a choice between applying defined Deemed-to-Satisfy Provisions or developing Alternative Solutions using existing or innovative products, systems and designs.

Provisions which may affect approaches to managing condensation risk in buildings are contained in the BCA.

6.3 BCA

For application of its provisions, the BCA defines ten Classes of buildings according to use. Volume One deals primarily with buildings of Classes 2 to 9, which include residential buildings (mainly with multiple occupancies), commercial buildings and buildings of a public nature. Volume Two applies to Class 1 and Class 10 buildings (houses and their outbuildings such as sheds and carports).

Volume One has a companion Guide, in a separate document, which offers clarification, illustration and examples of the Volume One provisions. The Guide is not called up in legislation and cannot override any of the BCA requirements. It refers only to the national version of the NCC and does not cover any variations made by individual States or Territories. Similar, but briefer, guidance to the application of Volume Two appears in Explanatory Information boxes embedded within the text of Volume Two itself. Clause 1.1.8 of Volume Two notes that these elements of the Housing Provisions are non-mandatory and need not be adopted to the meet the requirements of the Housing Provisions.

6.4 BCA References to Condensation

Many of the humidity-related risks discussed in the Handbook might be considered implicit in the Objectives of Part F1 of Volume One and Part 2.2 of Volume Two, which both address Damp and Weatherproofing. The two volumes share a common objective:

OBJECTIVE (FO1 in Volume One or O2.2 in Volume Two – FO1 partially shown here)

The Objective of this Part is to–

(a) **safeguard occupants from illness or injury** and **protect the building from damage** caused by–

  (i) *surface water*; and

  (ii) **external moisture entering a building**; and

  (iii) **the accumulation of internal moisture in a building**

Despite this Objective, condensation is mentioned by name only in the energy efficiency provisions of the BCA. It is discussed by commentary in the Guide to Volume One Section J and by explanatory information embedded in Part 3.12 of Volume Two. Specific responses to the risks are not included in the energy efficiency elemental Deemed-to-Satisfy Provisions. As noted in the Preface, this non-regulatory approach recognises the complexity of the environmental, building construction and behavioural factors which contribute to condensation risk and its effective management.

Other requirements within the NCC which may influence choices made in dealing with condensation and associated risks, include the Performance Requirements for ventilation (in Part F4 of Volume One and Part 3.8.5 of Volume Two) and for bushfire safety (in Part G5 of Volume One and Part 3.7.4 of Volume Two).

6.5 Australian Standards

Referenced documents adopted through the BCA 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 BCA 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.

Design and installation standards

AS 1562.1—1992 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.

BCA Volume One refers to this Standard to determine the structural resistance of metal roofing in non-cyclonic areas in B1 and it forms part of the Deemed-to-Satisfy Provisions for roof coverings in F1.5. References in Volume Two occur in 3.5.1.0 and 3.5.3.0, where it serves as an Acceptable Construction Manual for metal roof and wall cladding.

The Standard has a non-mandatory Appendix A, titled Roof Ventilation, Water Vapour and Condensation, which suggests that "condensation is one of the biggest single items contributing to the deterioration of buildings". It also notes that "it 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 placed "on the warm side of the structure". "Vapour barriers", in this context, implies materials which are effectively impermeable to water vapour. The Appendix also notes that the warm side reverses in "air conditioned buildings in hot, humid climates" but does not address climates where the "warm side" can change from season to season.

AS/NZS 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.

BCA Volume One refers to this Standard in F1.5, where it forms part of the Deemed-to-Satisfy Provisions for roof coverings. In Volume Two, 3.5.1.0 identifies the Standard as an Acceptable Construction Manual for corrugated fibre cement roof cladding.

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). A1 advises that “climatic conditions in many parts of Australia are such that condensation [on the underside of roofing] may occur” and suggests that “in the case of fibre-reinforced cement roofs however, the presence of this phenomenon generally causes no trouble because of the insulating properties of the material”.

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/NZS 1562.3—1996 Design and installation of sheet roof and wall cladding Part 3: Plastic Sheet Roofing

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/NZS 4256 Plastic roof and wall cladding suite of standards.

BCA Volume One refers to AS/NZS 1562.3, along with AS/NZS 4256 Parts 1, 2, 3 and 5, in B1.4, where they apply for determining the structural resistance of plastic sheet roofing in non-cyclonic area. Volume One, F1.5 also refers to both Standards, where they form part of the Deemed-to-Satisfy Provisions for roof coverings. BCA Volume Two, 3.5.1.0 identifies this Standard and AS/NZS 4256 Parts 1, 2, 3 and 5 together as Acceptable Construction Manuals for plastic sheet roof cladding.

Unlike Parts 1 and 2 of the AS/NZS 1562 standard series, Part 3 does not comment on condensation issues.

AS 2050—2002 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/NZS 4200 Parts 1 and 2.

BCA Volume One refers to this Standard in Part B1 for structural requirements for roofing tiles and in Part F1 for the fixing of concrete roof tiles in non-cyclonic areas. In 3.5.1.0 of BCA Volume Two, AS 2050 is an Acceptable Construction Manual 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—2010 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 Part 2, provides simplified details for the construction of the masonry.

BCA Volume Two refers to AS 4773 Parts 1 and 2 in the Deemed-to-Satisfy Provisions of Part 3.3 as an Acceptable Construction Manual, for masonry, in 3.10.1 for buildings in high wind areas and in 3.11.6 for structural resistance of materials and forms of construction for masonry.

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.

Insulation and building membranes

AS/NZS 3999—1992 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 also considered in Section 2, Pre-installation Considerations and Inspection.

This Standard is not referenced in the NCC.

The guidance on condensation assessment highlights the need to consider using vapour retarders, ventilation or additional ventilation to reduce the potential for condensation. Where vapour retarders are specified, in conjunction with bulk insulation, they are to be installed on the side which is warmer during the season when conditions conducive to condensation exist.

Further detail is provided in notes within the Standard and through reference to the British Standard BS 5250 Code of Practice for Control of Condensation in Buildings.

Drafting Note:

AS/NZS 3999—1992 is being revised and updated by the Australian Standards Committee BD-058. The revised Standard is due for publication in late 2013-early 2014.

AS/NZS 4200.1—1994 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, 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.

BCA Volume One refers to this Standard in F1.6 where sarking materials used for weatherproofing roofs and walls are required to comply with AS/NZS 4200 Parts 1 and 2. Likewise, BCA Volume Two 3.5.1 references AS/NZS 4200 Parts 1 and 2 as an Acceptable Construction Manual for roof cladding.

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

AS/NZS 4200.2—1994 Pliable building membranes and underlays—Part 2: Installation requirements

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

BCA Volume One refers to this Standard in F1.6 where sarking materials used for weatherproofing roofs and walls are required to comply with AS/NZS 4200 Parts 1 and 2. Likewise, BCA Volume Two 3.5.1.0 references AS/NZS 4200 Parts 1 and 2 as an Acceptable Construction Manual for roof cladding.

Appendix A 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 suggests consulting additional literature available from the CSIRO, BRANZ or ASHRAE (Commonwealth Scientific and Industrial Research Organisation, Building Research Authority of New Zealand and American Society of Heating, Refrigerating and Air-conditioning Engineers, respectively) when building in areas where condensation is likely to occur. It also notes that, where condensation is likely to occur, the appropriate use of a pliable building membrane as a vapour barrier, thermal insulation, or both, can be effective as a preventative measure.

AS/NZS 4859.1—2002 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 the installation of insulation is provided in AS 3999 and AS/NZS 4200 Part 2. Reflective insulation with a prime function as a sarking or vapour barrier is covered by AS/NZS 4200 Parts 1 and 2.

BCA Volume One refers to the Standard in the Deemed-to-Satisfy Provisions of J1.2 and Specifications J5.2 and J5.4 for the testing of insulation materials, as does BCA Volume Two in 3.12.1.1 and 3.12.5.1.

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

Bushfire prone areas

AS 3959—2009 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 specify 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 Bushfire Attack Level (BAL) which is a measure of the severity of a building’s potential exposure.

In a designated bushfire prone area, G5.2 in BCA Volume One requires certain residential buildings to comply with Australian Standard AS 3959 in order to meet the Deemed-to-Satisfy Provisions of Part G5. Similarly, 3.7.4.0 in BCA Volume Two refers to the same Standard as an Acceptable Construction Manual for compliance with Performance Requirement P2.3.4.

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.

6.6 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 assessment methods are mostly based on multi-variable calculations and enacted through computer simulation tools. The summaries below describe the scope of some of these standards and outline the nature of their content.

ASHRAE Standard 160-2009 Criteria for Moisture-Control Design Analysis in Buildings

For United States conditions, ASHRAE Standard 160-2009 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 [but the] 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". ASHRAE Standard 160 is termed "a national voluntary consensus standard".

The content of ASHRAE Standard 160 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:

Criteria for selecting analytic procedures

The ASHRAE Standard 160 requires the use of a transient analytic procedure with a maximum time step of one hour. To comply with the Standard, the procedure must be able to calculate:

- the transfer of heat energy through the building fabric, including the temperature effects caused by water changing between its solid, liquid and gaseous states (or phases);
- material properties affected by moisture content;
- the transport of water (as liquid or vapour) by capillary suction, deposition on surfaces, storage in materials, vapour diffusion and by liquid water leakage; and
- the effects of any ventilated cavity which is included in the design.

In addition to being able to calculate these outputs, the selected procedure must also report the temperature and relative humidity at each surface and interface between layered materials; the average temperature of each material layer; and the average moisture content of 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.

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; and
- rain load on walls.

Whilst some of these parameters might be transferable to Australian locations and conditions, caution should be exercised in their use.

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.

The ASHRAE Standard 160 cites two other ASHRAE Standards as references:

- ASHRAE Standard 55-2004, Thermal Environmental Conditions for Human Occupancy;
- ASHRAE Standard 62.2-2007, Ventilation and Acceptable Indoor Air Quality in Low-Rise Residential Buildings.

Both of the referenced standards have been updated since the release of ASHRAE Standard 160-2009. ASHRAE Standard 55-2010 and ASHRAE Standard 62.2-2013 are the current versions at the time the Handbook's publication.

Three annexes, which are not necessary for compliance with ASHRAE Standard 160-2009, include flowcharts for moisture-control design using the Standard and for finding indoor design humidity, a commentary on the Standard and a bibliography.

British Standard BS 5250:2011 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 ISO 13788, noting its limitations (such as ISO 13788's 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 ISO 13788 are also described whereby it does not apply to cold pitched roofs, with insulation provided at the ceiling level.

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 (AVCLs). 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.

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

This Standard is the United Kingdom 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 EN ISO 13788 deals only with steady-state conduction of heat and with vapour diffusion, 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 moisture entrained during construction;
- accumulation of interstitial condensation due to wintertime diffusion;
- moisture penetration caused by exposure to driving rain;
- condensation during summer due to moisture migrating from outside to inside;
- condensation on external surfaces to cooling by longwave radiation; and
- heat losses due to the transmission and evaporation of water.

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 relative humidity. The relative humidity 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 ASHRAE 160:2009 for the simplified method of determining design indoor relative humidity.

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 cancels and replaces the first edition (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”.

In discussing limiting sources of error, the Standard identifies several error sources arising from simplifications employed in calculations. The discussion concludes by advising that: “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.

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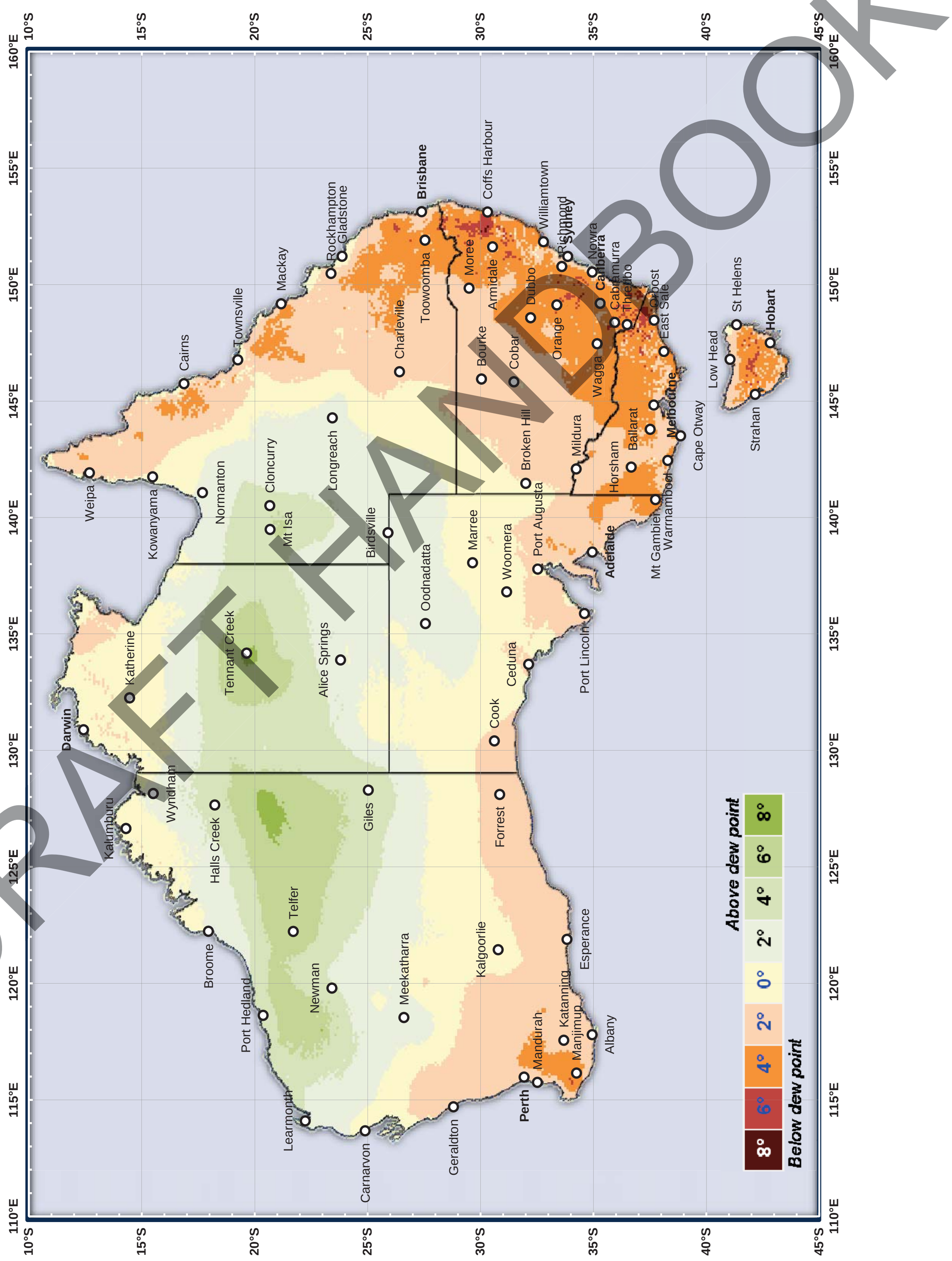
Appendix A Supplementary Material

A.1 Enlarged Exploratory Map

Figure A1.1 – Exploratory map of comparative outdoor condensation potential (enlarged version)



A.2 Climate Data for Preliminary Analysis of Condensation Potential

Drafting Note:

Appendix A.2 in the final document will provide selected climate data for the 160 Australian locations mentioned in Sections 4.1 and 4.5 in the body of the Handbook. Those details may assist designers, in or close to the locations covered, to perform the preliminary assessments of condensation potential suggested in Section 5.10. The assessments can include:

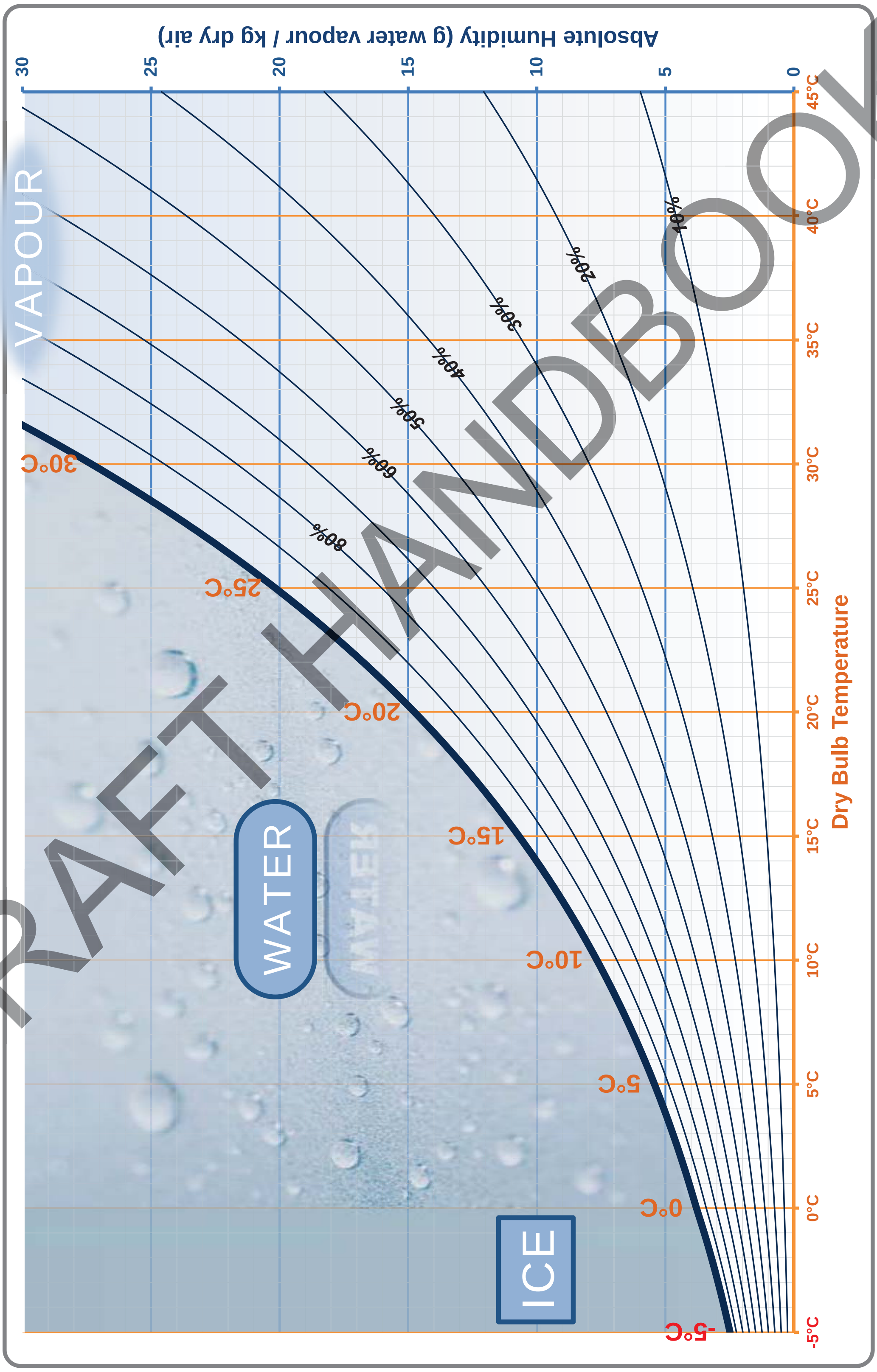
- roof cladding condensation check
  (outdoor monthly minimum temperature vs outdoor dew point)
- underside of sarking condensation check (in a ventilated roof)
  (outdoor monthly minimum temperature vs outdoor dew point)
- wall cavity condensation check
  (outdoor monthly mean temperature vs indoor dew point)
- sub-floor condensation check
  (annual mean temperature vs outdoor dew point)

For use with these methods, an uncluttered version of the standard psychrometric chart is included on the next page (in A.3). Its temperature range (on the horizontal axis) begins at minus 5°C to allow for use with colder climates. Its upper temperature is limited to 45°C, which is sufficient when dealing with monthly average temperatures, rather than climatic extremes.

A.4 contains a fully detailed version of the standard chart, provided by AIRAH, to illustrate the extensive information available to air conditioning engineers and operators on the behaviour of water vapour in air. The standard chart covers temperatures ranging from 0°C to 50°C. It also labels the dew point curve as “Saturation Temperature” and the absolute humidity (on the innermost right hand vertical scale) as “Moisture Content”.

A.3 Basic Psychrometric chart

Figure A.3.1 – Basic Psychrometric Chart for Climate Analysis



A.4 Standard Psychrometric chart

Figure A.4.1 – Standard Psychrometric chart supplied by AIRAH