An Australian Based Study On Airtightness and Moisture Management

Computer based simulation of the combined heat and moisture transport of wall assemblies; a roof construction review; and a field study of state-of-the-art construction practices in Australia

pro clima®

Content

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Glossary of terms

ABCB: The Australian Building Codes Board is a joint initiative of the Australian Government and state and territory governments, the ABCB regulates safety, health, and amenity and sustainability issues through the National Construction Code (NCC).

AccuRate: Is a CSIRO developed software tool. The software has been built on decades of scientific research and lessons from over a decade of the Nationwide House Energy Rating Scheme program. AccuRate enables house designers to model a house to a fine level of detail, calculate temperatures, heating and cooling energy requirements on an hourly basis, and assess a house's energy efficiency in any one of 69 different climatic zones in Australia.

ACH: Air change rate. See air changes per hour.

Air barrier, membrane: A layer that greatly restricts the movement of air under the normal pressure differences found across building elements. The thresholds for classification as an air barrier. This doesn't need to be capitalised. The Australian and New Zealand standard AS/NZS 4200.1 is achieved when an air resistance of ≥0.1 MNs/m³ is achieved when tested in accordance with ISO 5636-5.

Air barrier material: an impermeable material that retards air movement, such as a membrane or SOLID concrete.

Air barrier assembly: air barrier materials joined by sealing accessories into a contiguous impermeable layer, such as an airtight wall or roof.

Air barrier system: The collection of air barrier assemblies joined by air barrier accessories and components into a continuous barrier to air movement, building wide.

Air barrier intelligent: An airtightness membrane, which adjusts its diffusion resistance depending on the ambient conditions.

Air changes per hour: The number of times the air volume within a house is completely replaced with outside air in a one-hour time period under typical operating conditions.

Air changes cavity: The number of times which an air flow introduced into a volumetric cavity completely displaces the air in the cavity within one hour. For example, a ventilated cladding cavity.

Air control membrane: A membrane installed to limit air transfer between each side of the membrane (AS/NZS 4200.1).

Air control layer: A membrane or other material that is sealed at all junctions to limit air transfer between each side of the layer.

AIRAH: The Australian Institute of Refrigeration, Air-conditioning and Heating

Airtightness: Construction methods focusing on the elimination of all unintended gaps and cracks on the external envelope of the building.

AS/NZS 4200.1:2017: Pliable building membranes and underlays materials

AS 4200.2:2017: Pliable building membranes and underlays installation requirements

AS/NZS 4201.4: Pliable building membranes and underlays - Methods of test - Resistance to water penetration

ASHRAE: American Society of Heating, Refrigeration and Air-Conditioning Engineers

Assembly, building: The combination of building elements including sheeting materials, structural members, membranes and insulation as configured to form a roof, wall or floor. May be referred to as a wall assembly, roof assembly or generically an assembly.

Assembly, cladding: The combination of cladding material, battens and/or brackets to hold the cladding in place.

Assembly, framed: A framing structure for an specific purpose.

Assembly, gutter: Roof guttering and any clips brackets and/or fascia required to hold the gutter in place.

ASTM E96: Standard Test Methods for Water Vapour Transmission of Materials

ASV: Above Sheathing Ventilation. A dedicated ventilation pathway under the roof cladding material, specifically designed to remove moisture in winter and heat in summer utilising counter batten fixed vertically over the truss top chord or rafter clamping a taut pliable building membrane in position. The membrane may be placed over rigid boards, particularly at low pitches below 10 degrees.

BCA: The Building Code of Australia. Generally, refers to Volume 1 and/or Volume 2 of the National Construction Code (NCC). Volume 1 contains the requirements for Class 2 to 9 (multi-residential, commercial, industrial and public) buildings and structures. Volume 2 contains the requirements for Class 1 (residential) and Class 10 (non-habitable) buildings and structures.

BRANZ: The Building Research Association of New Zealand is an independent research organisation that uses an impartial evidence-based approach to improving the performance of the New Zealand building system. Their research has influence in the Oceania region.

Building class: The NCC groups buildings and structures by the purpose for which they are designed, constructed or adapted to be used, assigning each type of building or structure with a classification. The building classifications are labelled "Class 1" through to "Class 10". Class 1 is single dwelling housing or attached dwellings, each being a building, separated by a fire-resistant wall, including a row house, terrace house, town house or villa. Class 2 is a building containing two or more sole-occupancy units. All other classes 3-9 are excluded from this study as they are commercial buildings and include education, aged care, childcare, health care, office, retail, assembly buildings, storage, carparks, laboratory, public buildings which fall outside the scope of this study.

Building element: A floor, wall, roof, major structural component or window which adjoin together. Building elements are adjoined to form the entire building.

Building envelope: The parts of a building's fabric that separate artificially heated or cooled spaces from the exterior of the building; or other spaces that are not artificially heated or cooled.

Building membrane, pliable (or underlay): Pliable material, which may be installed to act as a sarking membrane. It may provide water control, thermal control, vapour control, air control, ember control or any combination of these.

Calculation, steady-state: A steady-state calculation is undertaken using a static indoor (°C, % RH) and static outdoor (°C, % RH) condition for a dewpoint calculation.

Calculation, transient: Dynamic simulations of coupled heat and moisture transfer. The methods have been validated worldwide and provide realistic simulation of hygrothermal conditions in building components and buildings under actual climate conditions.

Condensation: The process used to describe moisture formation on a surface as a result of moist air coming into contact with a surface which is at a lower temperature. As cool air is unable to retain the same amount of water vapour as warm air, excess moisture is released as condensation.

CSIRO: The Commonwealth Scientific and Industrial Research Organisation

DA07: Design Application Manual 07 was released by AIRAH into Australia in 2020. It defines the criteria for moisture control design analysis in buildings and is a modified text adoption of ANSI/ASHRAE Standard 160-2016.

Dew point: The temperature at which the relative humidity of the air reaches 100 %, at which time saturation occurs and water vapour contained in the air will begin to condense. The dew point temperature of the air depends upon the air temperature and the humidity of the air and can be determined using a psychrometric chart.

Energy Efficiency Council (EEC): The Energy Efficiency Council is a not-for-profit membership association for businesses, universities, governments and NGOs. Their cause is building a sophisticated market for energy management products and services that delivers healthy, comfortable buildings; productive, competitive businesses; and an affordable, reliable and sustainable energy system for Australia.

Foil: Thin metallic sheet material, usually of aluminium, used as a sarking membrane, vapour barrier or thermal insulation material.

Fibrous insulation: Fibrous insulation is a specific type of insulation that works by capturing air within the fibers, preventing heat transmission through convection. This type of insulation also limits heat conduction between molecules of gases by minimizing collisions between the particles. These insulation types will be of high vapour permeance. This includes all natural and synthetic fibre types; glasswool, rockwool, cellulose, polyester, wood fibre etc.

Film, microporous: An older technology used in vapour permeable membranes that utilises microscopic holes in a layer of polyolefin material. Microporous coatings and membranes rely on an interconnected network of tiny holes (pores) introduced by various means into an otherwise impermeable polymeric structure. Sheets of polymers can be produced with common salts incorporated which is washed out afterwards to leave voids/pores. Such holes (or pores) are too small to allow water droplets to pass through but are large enough to allow water vapour to pass through.

Hydrosafe®: The hydrosafe value quantifies the level of protection for your construction against increased indoor humidity levels during the construction phase (building moisture).

IAB: An Intelligent Air Barrier is a membrane which has humidity variable vapour permeability characteristics which allows optimal response to surrounding environmental conditions.

Infiltration: The unintentional or accidental introduction of outside air into a building, typically through cracks in the building envelope. Infiltration is sometimes called air leakage.

Interstitial condensation: Is when water vapour condenses on cold surfaces within an enclosed wall, roof or floor cavity structure, which can create damp conditions.

Kilowatt-hour, kWh: The kilowatt-hour (symbolised kWh) is a unit of energy equivalent to one kilowatt (1 kW) of power sustained for one hour. One watt is equal to 1 J/s. One kilowatt-hour is 3.6 megajoules, which is the amount of energy converted if work is done at an average rate of one thousand watts for one hour.

Mineral wool: Any fibrous material formed by spinning or drawing molten mineral (silicon dioxide) into glass wool or rock materials such as slag and ceramics into stone wool or rock wool.

Moisture content: Moisture content refers to the grams of water that is present in a cubic meter of a material.

Moisture, external: The penetration of moisture into the building cavity through various sources such as rain, capillary action, leaks, solar driven moisture, air movement and vapour diffusion.

Moisture, internal: Moisture generated by human activities inside a building, i.e. breathing, sweating, cooking, clothes drying or showering.

Moisture load: The added moisture to an assembly that may arise from the diffusion of water vapour, air leakage transported water vapour or liquid water leaking into an assembly.

Mould, invisible: Mould hidden within construction systems which cannot be seen by simply looking at the internal or external surfaces of the construction assembly.

Mould, visible: Mould that is easily visible on the surface of a construction system. Usually, the interior linings are the most concerning location for visible mould.

MVOC: Microbial volatile organic compounds are a variety of compounds formed in the metabolism of fungi and bacteria. The most obvious health effect of MVOC exposure is eye and upper-airway irritation.

n_{50}: Air changes per hour measured during a pressurisation test is reported at a nominal value of 50 Pa. It is the air flow through the building envelope at 50 Pa divided by the building volume. Sometimes also referred to as ACH50.

NatHERS: The Nationwide House Energy Rating Scheme calls upon software to assess a star value (from 0 to 10 stars) that is calculated based on the predicted annual Energy Load and the Star Band Criteria for each Climate Zone. The predicted annual Energy Load and the corresponding star rating band for the particular Climate Zone is the design's star rating for regulatory purposes.

NCC: The National Construction Code. It is an initiative of the Council of Australian Governments developed to incorporate all on-site building and plumbing requirements into a single code. The NCC sets the minimum requirements for the design, construction and performance of buildings throughout Australia.

Passive House: A building standard that is truly energy efficient, comfortable, affordable, and ecological at the same time. It is a construction concept and validation methodology that delivers a high-quality outcome that will deliver on the intended design.

qE_{50}: Air permeability Air flow through the building envelope at 50 Pa divided by the envelope area.

Relative humidity (% RH): The measure of the amount of water vapour in the air relative to the maximum amount of water that the air can hold at a given temperature.

Ridge vent: A opening built into the apex of a roof structure to allow air to be removed from the roofing system.

Roof sheathing: Timber boarding, plywood or other sheeting secured to rafters, trusses or purlins, as a base to which the roofing material is laid or fixed.

Sarking: A pliable, water-resistant membrane for use beneath the external roof or wall covering to collect and discharge any water that may penetrate, or water vapour that may condense on it. Historically has been combined with reflective foil. Also Called: water barrier.

Service cavity: A dedicated gap typically created using battens between an Intelligent Air Barrier (IAB) and the internal lining. Used to run, pipes, cables and conduits.

Soffit vent: A vent built into an eave lining to allow air into the attic space or into a structured ventilation cavity between the roof cladding and the roof Weather Resistive Barrier (WRB). See also Above Sheathing Ventilation.

Static modelling: See steady-state calculation.

Thermal bridge: A thermal bridge, also called a cold bridge, is an area of a building construction which has a significantly higher heat transfer than the surrounding materials.

TEEE: Thermoplastic Elastomer Ether Ester is a polymer used as a monolithic interlayer in modern vapour permeable membranes providing superior air barrier and water barrier properties with excellent strength characteristics. The polymer has excellent long-term durability, UV resistance, temperature resistance and is unaffected by corrosive environments.

Vapour barrier (VB): A thin layer of impermeable material, typically polythene sheeting, included in building construction to prevent moisture from migrating into the fabric of the building. This is classified as Class 1 or Class 2 membranes by AS/NZS 4200.1. Aluminium foil membranes are also classified as vapour barriers and may unintentionally prevent water vapour from escaping (drying) from the building fabric.

Vapour control membrane (VCM): A pliable building membrane designed to either allow or restrict the transfer of water vapour across the membrane. They range from Class 1 and Class 2 vapour barriers to class 3 and class 4 vapour permeable membranes in AS 4200.1.

Vapour diffusion: Vapour diffusion occurs through air and/or porous building products when there is a vapour pressure difference between indoor and outdoor air conditions. The rate of diffusion depends upon the permeability of the linings and materials that make up the building fabric.

Vapour permeance, water: Vapour permeance is a material's ability to allow water vapour to pass through it. The vapour permeance takes into account the material's thickness, so can only be quoted for a particular thickness of material. It is usually measured in µg/Ns ("Micro-grams per Newton seconds").

Vapour resistance, water: The vapour resistance of a material is a measure of the material's reluctance to let water vapour pass through. The vapour resistance takes into account the material's thickness, so can only be quoted for a particular thickness of material. It is usually measured in MNs/g ("Mega-Newton seconds per gram").

Ventilation: Ventilation is the removal of contaminated air and replacement with fresh outdoor air.

Ventilation, mechanical: Mechanical ventilation is the removal of contaminated air and replacement with fresh outdoor air by utilising power ventilators, fans or the like.

VTT: The WUFI® Mould Index VTT add-on was developed in collaboration between the Finnish research institute VTT and Fraunhofer IBP. Hannu Viitanen and Tuomo Ojanen have been dealing many years with the growth conditions of mould on wood and other building materials. The mathematic-empirical model predicts mould growth as a function of substrate material, temperature and relative humidity. For evaluation the so-called Mould Index (MI) was developed, which indicates the intensity of growth using an easy-to-understand six-point scale.

Water vapour partial pressure: The pressure the water vapour would exhibit if existing alone in the same volume and at the same temperature.

Weathertightness: (A building) sealed against rain and wind.

Wind barrier: A material which has air barrier properties in which wind will not blow through it.

WHO: World Health Organisation

WRB: A Weather Resistive Barrier is a flexible of rigid material in a construction system that forms the drainage plane. It allows water that has penetrated past the external cladding on either a wall or roof to drain away from the wall system. The two primary minimum performance parameters for a pliable building membrane to be suitable for this purpose is "water barrier" and "air barrier" designations according to as 4200.1. Also desirable are a degree of UV-stability for installation exposure and ≥100 °C temperature resistance for long term durability behind cladding systems.

WUFI®: A transient simulation software package developed by Fraunhofer institute for Building Physics in Germany. WUFI® is an acronym for "Wärme Und Feuchte Instationär" — which, translated, means heat and moisture transiency. WUFI® software uses the latest findings regarding vapour diffusion and moisture transport in building materials. The software has been validated by detailed comparison with measurements obtained in the laboratory and on IBP's outdoor testing field.

Preface

Australia is moving forward with energy efficiency of its housing stock and recently a connection to healthy buildings has been made. Specifically, there have been several recurring themes emerging in the race to zero energy; thermal stress on people, moisture issues and the effects this can have on the health of the occupants. When energy efficiency is implemented poorly unintended consequence of mouldy damp houses are possible, but when implemented well the inhabitants will be happier, healthier, and more resilient with economic benefits on a personal level as well as an economy wide scale.

This study outlines an in-depth scientific review of residential construction systems that assist in preventing moisture related side effects in increasingly energy efficient buildings.

In 2003 the residential housing provisions for energy efficiency were first introduced in Australia (3.5 - 4 NatHERS Stars), moving to 5 stars in 2006, 6 stars in 2010 and 7 stars in 2022. This generally means more insulation. More insulation results in colder surfaces and more convoluted airflow networks through the construction assemblies increasing the time moisture laden air has to condense onto cold surfaces or to be absorbed into materials.

Although there is limited history of energy efficiency regulations in Australia, there is substantial international evidence that the balance between energy efficiency and moisture become increasingly important as insulation levels and thermal performance increases. The effects of moisture accumulation in the building envelope then increase in prevalence and are often described as "unintended consequences" however moisture related side effects are to be expected and are even highly predictable in nature.

Internationally the imbalance of this relationship has been experienced in Europe, United Kingdom, North America and New Zealand to name a few:

- The Sick Building Crisis, EU.
- The Canadian Condo Crisis.
- The "Stuccopocalypse" in USA.
- The Leaky Building Crisis in New Zealand.
- The Commonwealth of Australia inquiry into biotoxin related illness

Where are we now?

The emerging problem is widely debated in Australia, but the basis of science and international learnings highlights that, the more insulated a building becomes, the greater the risk of moisture related issues if no preventive measures are employed. This results from the manipulation of thermodynamic forces for energy efficiency reasons. This then manifests as condensation on non-porous cold surfaces and high moisture content within the pores of cold or cool porous materials.

It is then possible that accumulation of condensate within the materials leads to high surface humidity and mould growth on these materials.

The prevalence of mould is unknown. Between December 2015 and February 2016, the Australian Building Codes Board (ABCB) conducted a survey of building practitioners to gather evidence on the extent of problems in Class 1 buildings (houses) and Class 2 buildings (apartments) in relation to condensation – one common cause of mould. That survey, which received more than 2,000 responses, looked at buildings aged from two to five years and from ten to fifteen years. According to the results, it appears that condensation is present in 40 % of all Australian homes [1]. An earlier estimate by the WHO in 2009 suggested that dampness may impact between ten and fifty percent of indoor environments in Australia [2].

In October 2018 a commonwealth inquiry into biotoxin related illness made seven recommendations, the main preventative measure called for was further research into the adequacy of current NCC requirements and standards in relation to the prevention of dampness and mould in buildings [3]. Energy efficiency, freedom from structural damage and a healthy indoor environment - rely on correct selection of materials and design of moisture management.

Good health depends on healthy living conditions

Coincidently, in Australia, asthma is the leading cause of disease in children aged 0–14 years, accounting for 17.9 % of the total burden in boys and 18.6 % in girls. Many researchers have supported a connection between damp housing and childhood respiratory symptoms. The contemporary code compliant houses in Australia may have inadvertently created ideal interior environments that promote mould growth. If the built environment is promoting mould growth, leading to sick building syndrome, it is a matter of serious concern, resulting from the design or technical flaws in the building fabric. [4]

Increased allergies and respiratory diseases

Excess cold and indoor humidity or dampness can generate and aggravate a range of illnesses, including allergies and respiratory diseases such as asthma. In addition, excess dampness can lead to mould growth, which has further negative health impacts. [5]

Increased public health spending

Asthma has a negative impact on a person's quality of life (for example inability to do sports, time spent off school by children, or the need to take medication). It also has a very severe impact on the economy [5], because of direct costs to the health system, including medication, hospital and out of hospital costs. The cost of asthma to the Australian community in 2015 was $ 28 billion.

The biggest component of the cost of asthma is the burden of disease, calculated as $ 24.7 billion, which includes the affect of disability and premature death [6]. It also has a cost in the terrible suffering endured by small children, who are often too young to understand asthma and frequently panic.

The cost of Chronic Obstructive Pulmonary Disease (COPD) to the Australian economy in 2008 was $ 98.2 billion. This includes costs of lower employment, absenteeism, premature death, living aids, home modifications, welfare payments and forgone taxation. The biggest cost of COPD was the burden of disease calculated as $ 89.4 billion (which includes the effect of disability and premature death) [7].

What causes asthma?

Although the underlying causes of asthma are still not widely known, it has been established that development of asthma is multifactorial and can result from the interaction of different genetic, environmental and lifestyle factors (AIHW, 2011 as cited in [8]).

The childhood asthma rate in Australia has been extensively studied for decades and attempts have been made to derive correlations between wet buildings, the presence of mould and rates of asthma (Peat et al. 1994; Phelan 1994; Ponsonby et al. 2000; Poulos, Toelle, and Marks 2005, as cited in [9]). Typical allergic characteristics which occur most frequently are – conjunctivitis, allergic rhinitis, bronchitis, skin eczema and nettle rash. In childhood, exposure to indoor mould might not just affect the respiratory health but also the overall health is impacted (Tischer and Heinrich 2013, as cited in [9]). Exposure to indoor moulds has also been associated with insomnia in adults (Tiesler et al. 2015, as cited in [9]).

Indoor lifestyle

People who live a modern lifestyle spend over 90% of their lives indoors and approximately two thirds in their homes [10] [11] [12]. It is therefore necessary to focus on the habitat in which we live, not just in the geographical sense, but especially on the related personal living environment and the outer shell, the building envelope. It is worth taking a particular look at our living and working environments in comparison with other countries.

The air we breathe is indisputably one of the key factors that contributes to respiratory diseases. In urban and industrial regions, air quality is often contaminated with toxic chemical and fine particulates. A significant amount of this external contamination adds to indoor generated contaminants leading to poor indoor air quality, the places we work, play and live.

A cold indoor environment means higher relative humidity (sometimes well over 80 %) due to the air's physical characteristics. This combination - cool and damp - in the long term, causes stress on the immune system and the respiratory tract.

High humidity levels resulting from low indoor temperatures favour the growth of mould on the surface of building materials. Mould needs no water to take hold or grow, a sustained high level of relative humidity (over 85 %) is sufficient [11] [13]. The 2016 scoping study funded by the Australian Building Codes Board "confirmed that there is a national concern about condensation in buildings constructed since 2004" [1].

Visible mould

The growth of mould on internal linings (visible mould) is caused by cold interior surfaces which arise in the vicinity of thermal bridges. Thermal bridges are (small) areas in constructions that allow energy to be conducted through building assemblies that are insulated. In other words, they are places where heat is rapidly transmitted to the colder side of the construction. There are two distinct types of thermal bridges:

Those caused by 1 – geometry and 2 – those caused by material change. Thermal bridges caused by geometry can be found, for example, in corners and junctions of building elements such as windows or in projecting ceilings, etc. Thermal bridges caused by materials can be found in thermally conductive materials such as those used in steel frame construction or uninsulated steel beams in external structural components.

Invisible mould

Mould within constructions (invisible mould) is also favoured by high levels of relative humidity in the living and working environment. In contrast to mould on the surfaces, the cause of this is primarily air infiltration through the building envelope, i.e., poor airtightness [14]. The indoor air that penetrates the gaps in the inner lining cools, this can then result in moisture accumulation in the construction, thus resulting in mould growth [11] [15]. Mould thrives in damp environments, and it has been demonstrated that water damage which persists for more than three days causes an increase in the levels of spores inside a building.

Health effects

In addition to cold, damp indoor environments, exposure to mould and mildew is significant in relation to the development of respiratory health and asthma [11] [16-21].

The adverse effect of dampness on respiratory health has been suspected for many years, and large cross-sectional prevalence studies on both adults and children have confirmed a positive relationship between indoor dampness and respiratory symptoms and asthma. Meta-analysis performed by Peat et al. [21] adds further support to these findings. In a Nordic review on the subject the authors conclude by stating:

"The review shows that "dampness" in buildings appears to increase the risk for health effects in the airways, such as cough, wheeze and asthma. Mould spores and mildew are considered to be allergens, as they irritate and stress the immune system. Allergic (extrinsic) asthma is far more widespread (approximately 85%) than non-allergic (intrinsic) asthma. The allergies are then named after what triggers them, for example, allergies to animal hair, pollen, dust mites, food, asthma, etc., but not after the actual cause" [21].

Although mould spores have no smell, microbial volatile organic compounds (MVOCs), which are excreted by mould and mildew, do have a smell. The compounds can have a negative impact, in particular on the health of people with a weak immune system: young children, the sick and elderly.

Finally, there are mycoses. These are fungal diseases in the body that can also have an impact on health. The allergenic and illness-inducing effect of mould in food has been well-known for years, but the fact that mould (spores and MVOCs) in the air also poses a threat is only gradually gaining recognition amongst the population.

The most important types of mould that trigger allergies are Aspergillus, Cladosporium and Alternaria. These are all types of mould that can occur in food as well as in the construction (on the surfaces as well as within the construction of the building). While gastric acid in our body acts as a barrier against mould in food - by attacking the mould spores - the lungs have absolutely no protection against the spores or other compounds produced by mould that are breathed in. Mould spores that are breathed in are then taken up directly by the body which then must fight to free itself of them. Essentially, the air we breathe that is contaminated with mould spores is more critical than food contaminated with mould [11] [22]. The mechanisms by which dampness is associated with respiratory symptoms and asthma are as of the current date still unknown. A relationship has been reported between allergic sensitisation to moulds and asthma severity [11].

The objective is thus to improve the quality of air and the quality of life in the living and working environment, to ensure it is a warmer, drier, less mouldy and healthier. By taking relatively simple measures it is also possible to create a healthy indoor environment with a high level of protection against structural damage and an energy efficient construction. This can be achieved by:

- Intelligent and fully functional sealing, usually of the inner building envelope (airtightness and intelligent moisture management)
- Better thermal insulation (without thermal bridges and with greater thickness of insulation)

World class homes for Australia

The WHO has called for indoor temperatures to be at least 18 °C, even in the winter, particularly to avoid the health impact and burden on the immune system and the respiratory tract [2]. The prevention of mould growth in the living environment has to become a matter of course in the future. A healthy living environment - warm, dry and free of mould - is especially important for young children, who spend most of the early part of their lives in enclosed spaces and experience their formative years indoors. Their health is at stake. Elderly and sick people also require higher temperatures and lower humidity to safeguard their health.

Not-for-profit organisations such as the EEC support the application of building methods to promote a healthy living environment and energy efficiency.

Independent analysis of the world's 25 largest energy consuming countries ranked Australia as the worst developed country for energy efficiency policy and performance. This is a huge issue for our nation as it means our buildings are contributing to poor health outcomes for Australians [23].

The Energy Consumers Australia "Multiple Impacts Framework" points to the considerable body of evidence indicating that the non-energy benefits (such as increased home comfort and better health) could be of greater value than the energy savings [24].

The Framework includes the impact on household health and wellbeing, including direct and indirect impacts of improved thermal quality and reduced dampness [25].

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"Health is not everything, but without health, everything is nothing."

Arthur Schopenhauer (1788-1860)

Executive summary

This study outlines construction solutions to achieve low energy, healthy and durable housing for future generations. A desktop analysis using WUFI® Pro software shows that in space conditioned housing, the incorporation of Intelligent Air Barriers (IAB) on the inside of framed wall assemblies in Australia will almost completely eliminate the risk of mould within walls in all climates except the tropics.

The severity of wind and rain in tropical climates necessitates the use of high-quality weatherproofing solutions for walls incorporating rigid boards and full adhesive weather resistive barriers to withstand the extreme wind conditions. This combination of rigid board plus full adhesive membrane also happens to deliver a level of vapour resistance that is as vapour permeable as possible but only as vapour resistive as necessary (humidity control). This maximises drying to deliver dry healthy wall systems. An IAB is not needed in the tropical Building Code of Australia (BCA) climate zone 1.

A review of international research suggests that the solutions for optimal moisture management and summer heat protection for trussed roofs, cathedral, or skillion roofs will always benefit from a structured ventilation cavity between the roof cladding (metal or tiles) and a well installed Weather Resistive Barrier (WRB) membrane. This strategy is known as Above Sheathing Ventilation (ASV) or above membrane ventilation. The exact regional solutions for roofing across the Australian continent have not been specifically defined but the issues have been clearly outlined, including the design trade-off between roof colour, ventilation strategies, bushfire ember protection, vapour permeability of materials and the use of IAB on the inside of the structure.

Light coloured roofs clearly provide a benefit for summer heat management and reduction in the building cooling energy demand and broader benefits of reduced heat island effect in urban centres if used broadly. Light coloured roofs are highly effective in reflecting solar energy back to the sky keeping the roof cladding cooler in summer, however, this also results in colder roofs in the winter. Light roofs benefit all major Australian capital cities. They help regulate the temperature in climates were there is extreme heat. These benefits include the cool temperate regions of Australia which can have extreme summer heat. The risk is that it reduces the drying potential compared to a darker roof as there is less heat to force water vapour back towards the inside (back diffusion drying potential). The use of interior IAB systems allow light coloured heat reflective roof cladding to be used safely across a wider range of climate zones. It reduces the amount of water vapour from the inside living space from reaching the cool roof cladding while still allowing back diffusion drying potential. The intelligent vapour control function (humidity variable membrane) with a light-coloured roof, delivers optimised summer and winter performance.

For flat roofs this study introduces the fundamental basis of implementation of water vapour and condensation control strategies in low slope ("flat") framed roof systems with or without fibrous insulation in the structural rafters. The inverted warm roof with all insulation placed above the framed structure with appropriate water barrier membranes is ideal. However, this is not always practical from a building height, cost and/or detailing perspective. In any scenario where insulation is placed into the framed roof structure an IAB will eliminate the risk of water vapour intrusion by convection or diffusion into the roof structure to reduce the risk of moisture damage by condensation.

There are no definitive roofing solutions outlined on a climatic basis within this study revision. This is due to the number of variables involved, the actual solution for any given climate will rely somewhat on the expertise of current industry practitioners as the solutions develop and evolve over the coming years. This report does however outline solutions which provide the highest levels of moisture safe design, providing certainty and low risk of mould and decay across all climate regions (excluding BCA climate 1). These lowest-risk solutions always incorporate an IAB at the ceiling line when insulated framed structures are preferred. This prevents roof space humidity issues and maximises drying potential.

IAB systems must always create a continuous airtight layer between the floor system, framed wall and roof structure for full effectiveness which is already well established and implemented widely by Australian builders. These connection details are important and have been refined by Australian builders and tailored to our construction techniques and processes as outlined in this study.

The key to effective implementation to balance energy and moisture is to utilise fan pressurisation testing to AS/NZS ISO 9972 (Blower Door testing) to ensure good workmanship of IAB systems. Tight buildings ensure maximum control over energy loss and uncontrolled moisture migration within construction assemblies.

Tighter buildings provide more control and with correctly implemented IABs in framed construction will provide predictable outcomes, every time.

This study is not just theoretical but lays out numerous innovative and practical solutions for moisture control. Many builders and companies in the Australian construction industry are already implementing building science principles to achieve healthy, durable and energy efficient buildings using locally available products and supply chains.

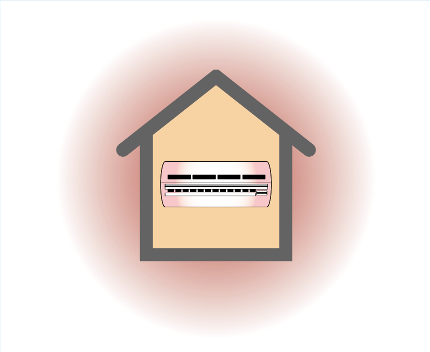


Figure 1.1: Non-airtight building envelope; The consequences are:
- Low indoor temperatures in the winter, despite high heating costs
- High indoor temperatures in the summer during daytime
- Unhealthy indoor environment

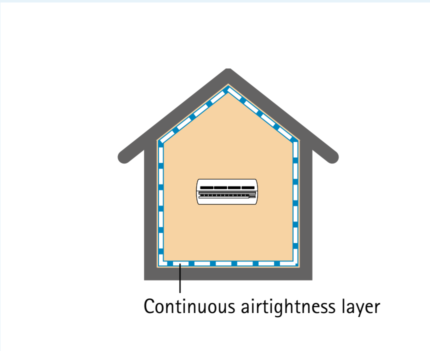


Figure 1.2: An airtight, insulated building envelope; An insulated construction with airtight sealing that works offers:
- A comfortable indoor environment
- Low heating costs
- Protection against structural damage due to moisture and mould

Figure 1.3: Mould in the bulding structure; Constructions that are not airtight do not only result in mould on the inner surfaces of structural components, but also in mould within the construction.

1. Introduction

This study describes the building physics of:
- Moisture and air
- Moisture and constructions
- Moisture and building materials
- Moisture and mould
- Moisture and intelligent membranes
- Moisture and ventilation systems.

It presents possible solutions for living in a healthy and energy-efficient environment free of structural damage.

1.1 The building envelope – protection for the living environment

The building envelope, i.e. the walls, floor and roof, separates the living environment from the outdoor environment. It protects the residents from the elements and aims to make them independent of environmental influences.
Wall and roof elements are subjected to particularly high stresses due to the difference in the inside and outside environments.
Uninsulated constructions, as were normal for a long time in Australia, provide little protection against the outdoor environment and the elements. As well as a lack of thermal insulation, Australian buildings have typically been air and water vapour permeable, with no airtight sealing layer. This means that air is able to penetrate and escape from the structure at a relatively high flow rate. Due to the high flow rate there is low tendency for condensation to form, and thus a lower risk of mould growing within the construction.
However, uninsulated constructions are difficult to heat (or cool down), resulting in low (high) indoor temperatures in the winter (summer), which are almost in the same range as the outdoor temperatures. Depending on the ambient climate this is accompanied by high levels of relative humidity. Mould generally forms on the cold surfaces, thermal conductive areas of the building such as structural or non-structural uninsulated wall and roof construction assemblies.
A consequence of this is a very poor and, importantly, unhealthy living environment. If houses were heated to the minimum requirement of 18 °C there would be excess heating costs. Power bills are typically not as excessive as they could be in Australia, but not because buildings are energy efficient. Buildings are simply too expensive to keep comfortably warm in the winter, so many occupants opt to under heat them, and suffer discomfort. The effect is that in the winter it is too cold indoors, and in the summer it is too warm, see Figure 1.1.
Insulated constructions assemblies are fundamentally different. Thermal insulation that works increases the surface temperature of building components on the inside. This results in a comfortable environment and helps to cut heating costs in the winter and cooling costs in summer. The relative humidity indoors is lower in the winter and the living environment is healthier, see Figure 1.2.
However, thermal insulation only works if the construction is protected from air flowing through it either from inside or from outside. Convection loops either within or around the insulation layer can also create problems as moisture is free to travel with the air. Constructions that are not airtight not only result in mould on the inner surfaces of construction components, but also in mould within the building envelope. This is due to the low flow rate of the air where it has more time to cool down and condense on to cool surfaces. This results in a poor living environment, which – though warmer – is more prone to mould within the construction assemblies, see Figure 1.3.
The transport of moisture within the construction follows the law of equilibrium: both insulated buildings and uninsulated buildings attempt to equalise to the ambient environment on each side. Towards the middle of the construction - depending on the insulating material used - the temperature and moisture level approach the mean level between inside and outside. Over the course of the day and through the seasons the roof and walls are constantly adapting to the changing conditions and influences.

1.2 Protection from mould and heat loss

The air control layer protects the insulation from moisture accumulation and condensation from the inside, ensures that the insulation operates effectively and provides a healthy indoor living environment.
The thermal insulation separates the indoor climate from the outdoor climate. The temperature difference between the two sides always drives energy towards equilibrium. This induces an air flow. In winter the warmer air from inside the building transfers through the building elements to the outside. Adding an air control layer prevents this air flow, and therefore the loss of heat to the outside.

If indoor air were allowed to pass freely through the thermal insulation, it would increasingly become cooler the further it penetrates towards the outside. If the dew point is reached somewhere into the insulation, then condensation will occur. Condensation may cause considerable damage to the building and its components. Load-bearing structural elements may rot and lose their strength.
Similarly, moisture also promotes the development of harmful mildew and mould. A vapour/air control layer on the inside of the thermal insulation helps to avoid such structural damage.

1.3 Ideal construction

The wind control (Weather Resistive Barrier [WRB]) layer is critical for the performance of the insulation. Mounted on the outside of the thermal insulation, it prevents cold outside air passing through the outer insulation layers. Still air is an excellent insulator. It is the trapped air between insulation fibres that creates the insulating effect of cellulose, wood fibre, hemp, wool, mineral fibres, etc. The WRB thus ensures the effectiveness of the thermal insulation and prevents the localised cooling of the surfaces facing the inside of a room. The WRB provides protection for wind washing in ventilated roof systems with additional water control for protection from secondary condensation or accidental storm leaks. See Figure 1.4.

Insulation by stationary air
Unprotected insulation: Air movement in a porous structure reduces the insulating effect. See Figure 1.5.

Protected insulation material
Protected insulation: Where no air movement is possible a porous structure provides effective insulation.
An example: The thermal insulation effect of a woolen jumper is based on the stationary air inclusions in the fibres: as soon as a cold wind starts to blow, the insulation effect decreases. However, the insulating effect is restored if a thin windbreaker is worn, which itself has no significant insulating function, over the jumper. See Figure 1.6.

Airtight on the inside, windtight on the outside
For this reason, the insulation material is sealed on all sides in the ideal insulation structure: outside with the weather resistive layer, e.g. which may be a pliable membrane (commonly known as sarking or underlay) or rigid sheathings (commonly known as rigid air barriers). that is open to diffusion, and on the inside with an airtightness layer.
The windtightness stops cold outside air flowing through the insulation. The airtightness provides protection against the entry of humid indoor air and thus against condensation and mould.
Note: Faultless installation work is important when installing air sealing, as leaks in surfaces and at joints will have consequences. See Figure 1.7.

1.4 Saving energy

Inadequate airtightness and its consequences.

Building envelope unsealed: High heating costs
Even very small leaks in the vapour control layer – such as those that arise due to faulty adhesion between membrane overlaps or joints – have far-reaching consequences. This type of weakness has the same effect as a continuous gap between the window frame and the walls – and of course nobody should tolerate such a gap! Accordingly, gaps in the vapour control layer should be given the same attention.

Sealed building envelope: Low costs
The higher heating costs caused by faulty seals lead to reduced cost-effectiveness of the thermal insulation for the building owner.
A study by the Institute for Building Physics (IBP) in Stuttgart (Germany) showed that the U-value (1/R-value) of a thermal insulation structure gets worse by a factor of 4.8. When applied to a practical case, this means that the same amount of energy is required for heating a house with a living space of 80 m² where airtightness leaks are present as would be required for an airtight house with a floor area of approx. 400 m².
The uncontrolled entry of air can also have a negative impact on the indoor environment, e.g. cold draughts in the winter, or overheating in the summer. [26]

Only a gap-free thermal insulation structure provides the full insulation value
According to a publication by Australian Bureau of Statistics "households in Climate Zone 1 were the highest consumers of electricity, consuming an average of 153.6 kWh of electricity per week (24 %

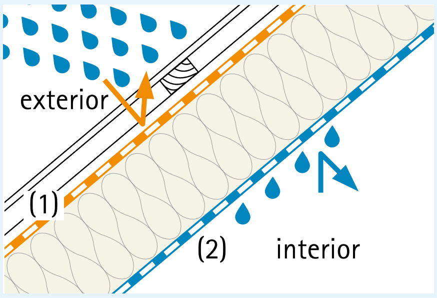


Figure 1.4: Ideal construction, airtight on the inside and wind- and weathertight on the outside; (1) WRB, (2) IAB

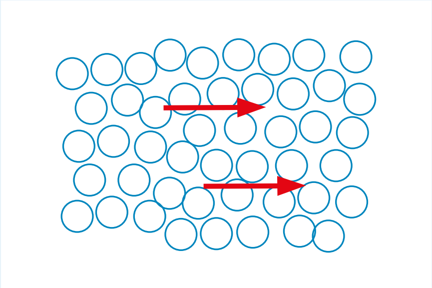


Figure 1.5: Insulation by stationary air, unprotected insulation

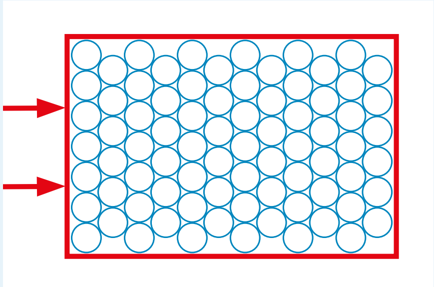


Figure 1.6: Protected insulation material

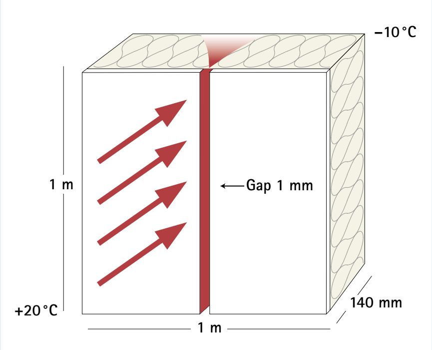


Figure 1.7: Dry cold air penetrates through gaps

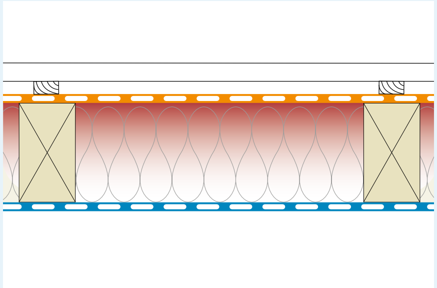


Figure 1.8: Cool rooms during summer heat, airtight and windtight roof construction prevents heat flow by convection

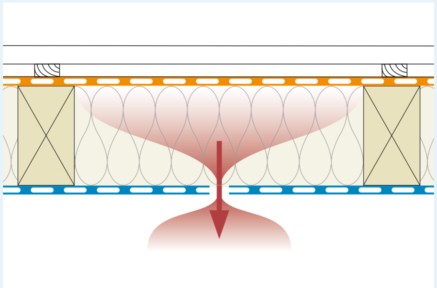


Figure 1.9: Warm air penetration, non-airtight roof construction

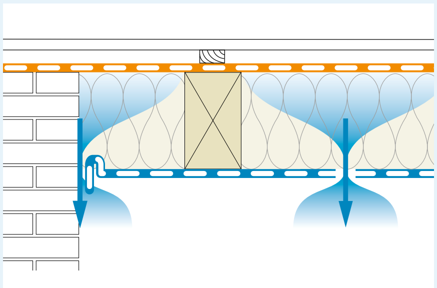


Figure 1.10: Dry cold air penetrates through gaps under wind effects, non-airtight connection, the airtight building envelope is not continous and closed

above the national average), likely reflecting higher cooling requirements and types of cooling systems used in this zone. In comparison, households in climate zone 6 consumed an average of 115.7 kWh of electricity per week (6 % below the national average)."[1]

A Passive House may only require a maximum of 15 kWh/m²a – to maintain a very healthy and comfortable indoor temperature between 20 °C and 25 °C throughout the whole year. Gaps in the airtightness layer of buildings lead to a significant increase in the energy requirement per square metre of living space.

The IBP studied a 1 x 1 m sized structure with a thermal insulation thickness of 140 mm. See Figure 1.7.

With a joint-free, airtight design, the previously calculated thermal performance of 0.30 W/(m²·K) was confirmed.

However, if the same structure features only a 1 mm wide gap in the air control layer, the U-value (1/R-value) deteriorates to 1.44 W/(m²·K). This means almost 5 times more heat is lost than with the airtight construction.

1.5 Healthy and comfortable living spaces

1.5.1 Indoor air quality and comfortable living environment

Although Australia is often considered a warm dry climate country, cold weather contributes towards 6.5 % of all deaths in Australia and hot weather contributes towards a further 5 % of deaths. [27]

Air sealing improves weather proofing, protects against mould, helps prevent dry air in the winter and keeps living spaces cool longer in the summer.

1.5.2 Exterior water penetration

In 2018 a Commonwealth inquiry found biotoxin-related illnesses have been reported to be associated with exposure to biotoxins such as mould in buildings arising from excessive moisture build-up from water damage. Buildings can become water-damaged after events such as leaks, heavy rain and flooding, and moisture can also enter a building through incoming air or through a build-up of condensation. [28]

1.5.3 Unpleasant room climate in summer

Thermal insulation in summertime is characterised by the time in hours that it takes for the heat present underneath the roof covering to reach the inside of the structure (phase shift), and by the associated increase in the interior temperature in comparison with the exterior temperature (amplitude damping).

1.5.4 Cool rooms during summer heat

The phase shift and amplitude damping are calculated for heat protection in summer. Dedicated ventilation strategies behind the cladding combined with airtight thermal insulation structure that the heat has to work its way though pore-by-pore is assumed here. See Figure 1.8.

1.5.5 Warm air penetration

Gaps in the airtightness layer result in airflow from the outside to the inside and therefore a high exchange of air as a result of the large difference in temperature and the resulting pressure. The thermal insulation can no longer reduce heat flow inwards and a too warm indoor environment results. See Figure 1.9.

1.5.6 Unhealthy room climate in winter

In the cold season, the heaters are running at full speed, which allows indoor air to dry out heavily, but the relative humidity in a home should be a comfortable 40 – 60 % during the heating period. A room climate that is too dry is bad for our health. The drier the air, the more dust particles buzz through the room air - water vapour is missing! Dust particles act as a base carrier for air-polluting particles: bacteria, viruses and microorganisms enter our body with every breath!

Dry air is not the direct cause of disease, but the impact of dry air on health is understandable: the activity of flu viruses increases disproportionately at low humidity levels. This explains why there is a higher risk of flu epidemics in winter than in summer due to the dry air.

Investigations in an American study from 2009 showed that the risk of infection with the influenza A virus is about three times higher at a low relative humidity below 35 % than at an optimal humidity of 50 %. There are two reasons for this: on the one hand, flu viruses can spread better in dry air and, on the other hand, they remain active longer in this environment than in moist air. [29]

1.5.7 Dry cold air penetrates through gaps

The frequently observed phenomenon of dry indoor air in winter is a result of the fact that cold outdoor air enters into buildings through gaps. If this cold air is warmed up by heating, its relative humidity reduces. See Chapter 1.13.2.
For this reason, buildings with poor airtightness tend to have air that is too dry in winter, and this cannot be significantly improved by humidification equipment. The consequence is an unpleasant room environment. See Figure 1.10.

1.6 Thermally insulated building envelopes

In the winter, thermally insulated buildings separate the warm indoor air, with its higher absolute humidity, from the cold outdoor air, with its lower absolute humidity.
In the summer, these buildings separate the warm outdoor air, with its higher absolute humidity, from the indoor air, with its lower absolute humidity.
This is accompanied by the risk of condensation (water condensing):
- on the external building elements in the winter
- on the internal building elements in the summer,

see Figures. 1.11 & 1.12.
Whether water actually condenses depends on the amount of moisture that penetrates the construction and the diffusion resistance of the various layers of the construction. In the winter, the temperature within the building envelope drops towards the outside. Depending on the humidity, there is a risk that the saturation temperature is reached. The saturation temperature is the point at which the air is not longer able to hold the moisture. It is therefore worthwhile to regulate the vapour diffusion flow.

1.7 Vapour diffusion flow

If the vapour diffusion flow is limited (for example, by an Intelligent Air Barrier) and if the construction is open to diffusion on the outside, a certain amount of moisture that penetrates the construction is able to escape again without forming condensation.
If, on the other hand, there is a diffusion-inhibiting or even completely impermeable layer on the outside, the vapour is prevented from passing through and there is a risk of condensation.
There is no condensation if less moisture enters on the warm side than can escape on the cold side, or if more moisture can be given off on the cold side than enters the construction on the warm side.
There are thus two ways of influencing the moisture balance: On the warmer side, by limiting the diffusion flow, or on the colder layer by increasing the diffusion flow without loosing functionality of wind- and watertightness.

1.8 Vapour diffusion flow in the summer

Not only does diffusion take place in the winter from the inside to the outside, it also takes place from the outside to the inside in the summer. In the summer, the direction in which the moisture flows is inverted. The vapour partial pressure (the product of the temperature and the relative humidity) is then higher outdoors than indoors, see Figure 1.11. What is ideal in the winter is that a vapour barrier on the inside and a diffusion-open, vapour permeable layer on the outside can thus turn out to be detrimental in the summer, when the direction of diffusion is reversed. If you have the ideal situation for winter conditions, open to diffusion on the outside, you can end up with a lot of moisture penetrating from the outside in the summer. The vapour barrier on the inside then becomes a moisture trap on which the moisture from outside can condense, see Figure 12. In other words, in the summer there needs to be a diffusion-open, vapour permeable layer on the inside, instead of a vapour barrier or other diffusion prohibiting layers.

1.9 Intelligent moisture management

Intelligent moisture management that is capable of reacting to the current ambient conditions, i.e. by reducing diffusion in the winter and being permeable to permit diffusion in the summer, is ideal, see Figure 1.13 & 1.14.
These characteristics are provided by the Intelligent Air Barrier (IAB) pro clima INTELLO® PLUS with variable diffusion resistance, which is laid on the inside:
- diffusion-reducing in the winter, when the vapour diffusion flow is from the inside to the outside.
- diffusion-open in the summer, when the vapour diffusion flow is from the outside to the inside. See chapter 2.1.

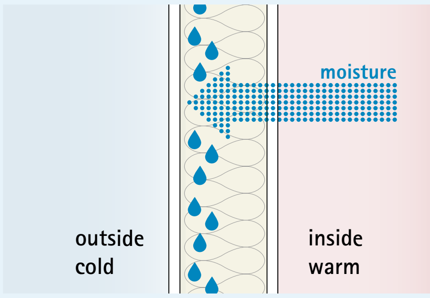


Figure 1.11: Condensation in winter, Outside colder than inside – condensation on the inside of the external surface

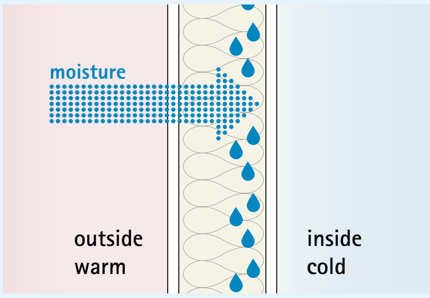


Figure 1.12: Condensation in summer, Outside warmer than inside – condensation on the outside of the internal surface

Condensation forms if more moisture enters on the warm side than can be escape on the cold side, or if less moisture can be given off on the cold side than enters the construction on the warm side.

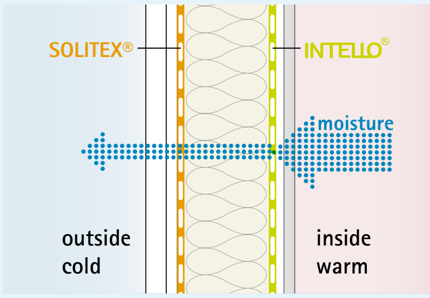


Figure 1.13: Intelligent moisture management in the winter

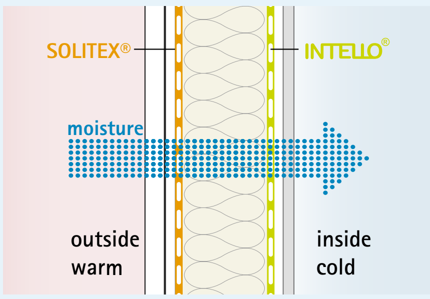


Figure 1.14: Intelligent moisture management in the summer [30]

Temp. [°C]	-10	-5	0	5	10	15	20	25
Saturation humidity [g/m³]	2.1	3.2	4.8	6.8	9.3	12.9	17.3	23.1

Table 1.1: Saturation humidity depending on temperature

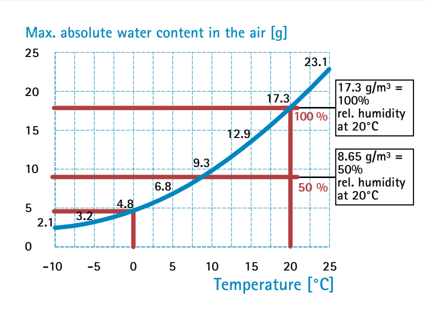


Figure 1.15: Determination of the absolute and relative humidity in the air
- Air can hold different amounts of moisture, depending on its temperature.
- At 20 °C max. 17.3 g/m³, at 0 °C max. 4.8 g/m³
- A relative humidity of 50 % is comfortable. At 20 °C this is 17.3 g/m³ x 0.5 = 8.65 g/m³

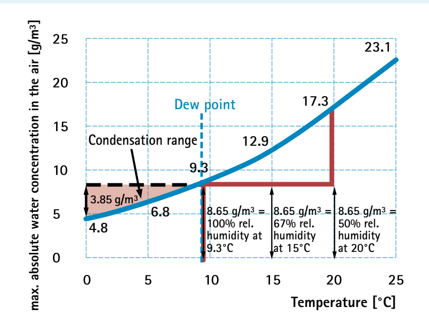


Figure 1.16: The physical behaviour of moisture in the air at 50 % RH
Under standard environmental conditions (20 °C/50 % RH) the dew point is reached at 9.3 °C. If the temperature drops to 0 °C, 3.85 g/m³ of condensation is deposited.

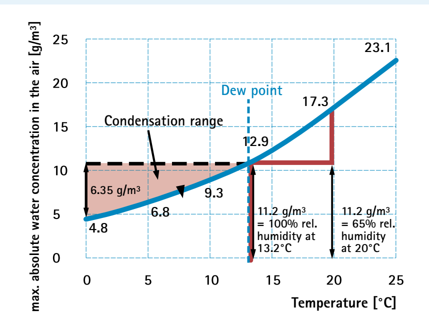


Figure 1.17: The physical behaviour of moisture in the air at 65 % RH
At an elevated RH of 65 % the dew point is already reached at 13.2 °C. If the temperature drops to 0 °C, significantly more condensation is deposited: 6.35 g/m³.

1.10 Moisture transport and living environment

Moisture can enter the building envelope in two ways.
Air can pass through the building envelope. Moisture laden air enters the construction through penetrations in the building envelope, e.g. driven by the difference in the air pressure on the two sides. If there is suction caused by wind on the outside, then warm indoor air flows into the building envelope, if there is wind pressure, air from outside flows into the building envelope. Pressure can also arise from buoyancy effects, these are often seasonal and therefore much longer lasting than wind pressure effects.
The second way for moisture transport is water vapour diffusion, which all building materials are confronted with. Air indoors has a different partial pressure to air outdoors, and the laws of physics determine that these difference will always try to reduce to the point where equilibrium is reached. This drive towards equilibrium causes moisture to move through the building envelope. The water vapour moves from the warm side to the cold side of the material, of the construction.
Both of these processes are capable of transporting additional moisture into the building envelope. An Intelligent Air Barrier can regulate the moisture balance and help keep the building free of condensation.

1.11 Mould resulting from damp building constructions

One of the most severe effects of moisture is the impact of mould spores on the health of people in buildings. Furthermore, continuous accumulation of moisture can results in structural damage. Structural damage occurs if the moisture uptake is higher than a construction's drying capacity. To avoid structural damage it is therefore necessary, to both, reduce the moisture uptake, and increase the construction's drying capacity.
Moisture can occur in buildings due to water from the outside leaking through the cladding and weather-tightness layers, which can be minimised with good design and careful construction. It can also occur from the inside through vapour diffusion, which can be calculated and allowed for. A third pathway also needs to be considered; that of moisture stress due to vapour convection. Vapour convection most commonly occurs as moisture transport through leaks in the airtightness layer. The moisture load due to accidental vapour convection through leaks in the inner lining of the building envelope is usually much greater than the calculable moisture load due to vapour diffusion. Hence the importance of attention to detail when designing and installing an air control layer.

1.12 Preventing structural damage and mould reliably

To prevent structural damage and mould reliably, it is necessary to concentrate on the drying capacity of a construction - both in winter and in summer.

1.13 The physical properties of moisture in the air

The physical properties of moisture in the air are described by two parameters:
- Absolute humidity
- Relative humidity (RH)

The absolute humidity is the amount of water vapour contained in a given volume of air. Absolute humidity is measured in grams of water per cubic metre of air (g/m³).
Relative humidity is a ratio of the absolute humidity and the maximum amount of water vapour that could be contained by the air mass at its current temperature. Relative humidity is given as a percentage (%).
The relationship between absolute and relative humidity depends on the temperature of the air mass because the temperature determines the amount of moisture that air can hold.
The amount of water vapour that the air can hold at a specific temperature is described as the saturation content. Warm air can absorb more water vapour than cold air. The temperature-dependent saturation values (100 % humidity) for the maximum water content are given in Table 1.1 and Figure 1.15. Air at a temperature of 20 °C can hold an absolute maximum of 17.3 g of water per m³ of air, whereas air at 0 °C can only absorb 4.8 g/m³.

1.13.1 During cooling: humidification, condensation, dew point

If air is cooled while remaining at the same absolute humidity, the relative humidity increases. For example, if air is at a temperature of 20 °C and 50 % RH it has an absolute moisture content of 8.65 g/m³. If this air then cools to 15 °C, the relative humidity rises to 67%.

Calculation:
Absolute humidity at 20 °C and 50 % RH = 8.65 g/m³
8.65 g/m³ correspond to 67 % of the saturation humidity (12.9 g/m³) at 15 °C = 67 % RH at 15°C, see Figure 1.16.
If the air cools even more, it will eventually reach the saturation temperature. In air at a temperature of 20 °C and with a relative humidity of 50 % (absolute = 8.65 g/m³) the dew point is reached at 9.3°C (saturation humidity of air at 9.3 °C = 8.65 g/m³).
Additionally if the air cools even more, water will form as condensation. This is why in warmer or even hot regions (like climate zone 1) dehumidification should be considered in a certain amount, see Figure 1.18. At 0 °C the saturation humidity is then 4.8 g/m³.
The amount of condensation is determined by calculating the difference between the saturation humidity at two different temperatures. In the example above, this is: 8.65 g/m³ – 4.85 g/m³ = 3.85 g/m³ of condensation.
This means that each m³ of air at 20 °C and 50 % relative humidity deposits condensation amounting to 3.85 g/m³ upon cooling to 0 °C. If this temperature drop occurs as air is passing through a construction, then the condensation will form within that construction.
If, on the other hand, one takes a higher relative humidity as a starting value, e.g., 20 °C and 65 %, then the moisture content is higher (65 % of 17.3 g/m³ = 11.2 g/m³), the dew point is higher (13.2 °C) and the amount of condensation upon cooling to 0 °C (6.35 g/m³) is larger. This means that each m³ of air at 20 °C and 65 % RH deposits condensation amounting to 6.35 g upon cooling to 0 °C while passing through to the outside of the building, see Figure 1.17.

1.13.2 During warming: drying, lower humidity, increased water absorption

During warming, the opposite takes place. The air can hold more and more moisture the warmer it becomes.
For example, take air at a temperature of 0 °C and 80 % RH. The saturation humidity (100 % RH) is 4.8 g/m³ absolute humidity. This corresponds to 3.84 g/m³ at 80 % relative humidity. If this air is then warmed to 20 °C it can hold a maximum of 17.3 g/m³ of water (= 100 %). The 3.84 g/m³ moisture in the air, absolute humidity, corresponds to a relative humidity of 22.2 % at 20 °C, see Figures 1.19 & 1.20.
That means that each m³ of air at 0°C that enters the building from outside only has a humidity of 22.2 % once it has warmed up to the room temperature of 20 °C. The result of this is that a warmer living environment generally tends to have a low relative humidity.
From a health point of view, a relative humidity of about 50 % is ideal, see Figure 1.21.
In an airtight building envelope the water vapour released and generated by the occupants (breathing, cooking, showering, house plants, etc.) contributes to the overall humidity. If the airtightness and ventilation are right, a comfortable ambient humidity of 50 % can be reached naturally. If the building envelope is not airtight, lower indoor relative humidity will be experienced during winter and higher indoor relative humidity will be experienced during summer.

1.14 Summary

- The humidification and drying processes within a building envelope depend on the physical behaviour of moisture in the air.
- These processes are driven by the natural tendency to reach an equilibrium.
- Moisture always travels from the side with the higher water vapour partial pressure to the side with the lower water vapour partial pressure.
- The water vapour partial pressure is defined as the product of the temperature and the relative humidity. Ignoring the humidity, this can be simplified by saying that the moisture travels from the warm side to the cold side.
- If a body of air warms up, the relative humidity drops.
- If a body of air cools down, the relative humidity increases and moisture is deposited as condensation if the air temperature falls below the dew point.
- Penetrations in the airtightness of the building envelope contribute towards a high level of moisture entering the construction.
- Constructions should be designed to provide: Protection against moisture in the winter, and a high drying potential in the summer.
- Using airtightness membranes with a variable diffusion resistance provide good protection against structural damage, even in the event of unforeseen moisture load.

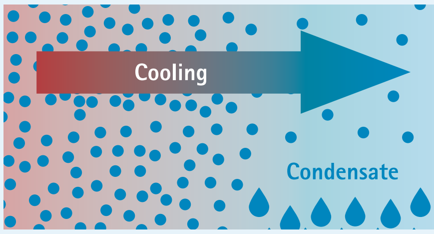


Figure 1.18: Condensation due to cooling
If warm air cools, condensate (condensation) may be deposited and there is a risk of structural damage and mould.

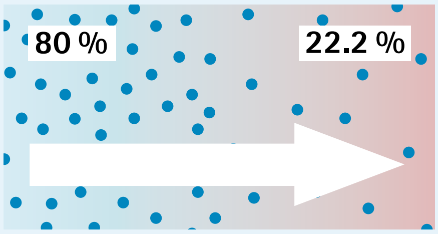


Figure 1.19: Reduction of the RH due to warming
If cold air enters a warm room, the relative humidity in the room drops.

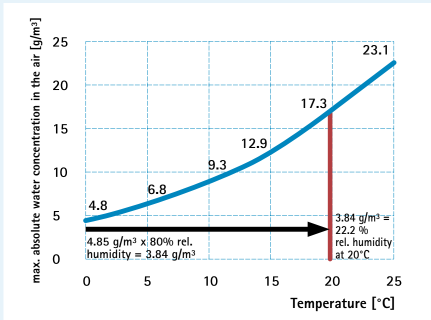


Figure 1.20: Air too dry due to warming
1 m³ of air at 0 °C and 80 % relative humidity is heated to 20 °C.
Consequence: The relative humidity in the room drops to 22.2 %. => too dry.
Comfortable and healthy air has a relative humidity of 50 % and 18 - 21 °C.

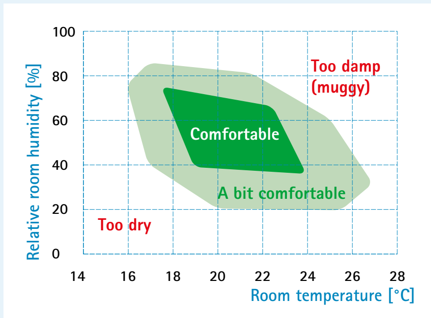


Figure 1.21: Comfort zone – Indoor humidity-indoor temperature

The ideal solution is to have an airtight building envelope that allows very minimal vapour diffusion flow to the outside in the winter, but allows the construction to dry out in the summer, either to the atmosphere or to the inside.

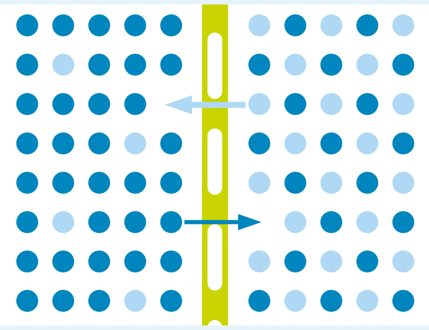


Figure 2.1: Diffusion, Moisture transport due to diffusion flow can be planned and allowed for

	MNs/g	MNs/g·m	µg/N·s	µ factor	s_d-value
MNs/g	–	MNs/g·m x d	1 : µg/N·s	–	s_d : 0.2
MNs/g·m	MNs/g : t	–	–	µ : 0.2	–
µg/N·s	1 : MNs/g	–	m	–	–
µ factor	–	MNs/g·m x 0.2	–	–	s_d x t
s_d-value	MNs/g x 0.2	–	–	µ x t	–

Table 2.1: Units of measurement conversion table

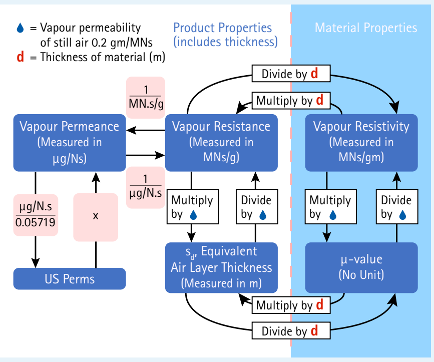


Figure 2.2: Measurement conversion

2. Paths of moisture transport

Some say, to build is a constant fight against water, against moisture. Everything reacts to it: people (a shower refreshes, thirst is quenched), the building material (swells and shrinks) and also the building components themselves (warps and twists), puddles form on surfaces and also mould needs moisture to grow and much much more. The following describes the paths of moisture into building and building structures.

2.1 Moisture transport: Vapour diffusion

Vapour diffusion is the term for the ability of water in its gaseous state to pass through a given material. Vapour diffusion is assisted by Brownian motion which describes the random movement of individual atoms, ions and molecules in a fluid, see Figure 2.1. Diffusion is driven by differences in concentration or pressure, so water molecules migrate through materials as well as through entire components in pursuit of equilibrium. So vapour diffusion will happen in every component of the outer building envelope.

To make sure that vapour diffusion will not cause damages we must take a look at the size of the vapour diffusion flow. The amount of moisture that is able to move through a material is dependent on two factors, the driving force or pressure of the fluid, and the resistance of the material. The vapour partial pressure of water in air is a function of the concentration of air molecules in the air, which is related to relative humidity. Vapour partial pressure is dependent on the temperature of the air.

Knowing the size of the vapour diffusion flow leads us to the need to regulate it. Regulation is done by the diffusion resistance of the single layers (materials) of the outer building envelope. The diffusion resistance of a layer (material) is a physical property related to density and porosity. For example, a lightweight material such as fibrous insulation is highly vapour open and will not provide resistance to the movement of gaseous water vapour, compared to aluminium foil which has such a high resistance to diffusion that it's a barrier to water vapour transfer.

Vapour diffusion resistance is determined by testing a material under specific laboratory conditions according to ASTM E96. The end result is a vapour permeance. See Table 2.1. and Figure 2.2. to convert between units.

Intuitively, it might be perceived that air has no resistance to water. But it should however be kept in mind that vapour diffusion resistance is describing the resistance of a substance to the flow of individual water molecules in a gaseous state. As per Brownian motion, vapour movement through the material (including air) occurs by way of molecules randomly bumping into each other. The denser the material, the more molecules there are to impede the overall movement of water molecules through a given volume, and the more resistance there will be.

From the basic physical material data of the material and the local climate it is possible to determine the amount of moisture that will diffuse through a construction. The following provides an example of the order of magnitude: plasterboard is diffusion-open and has a low moisture vapour resistance. This characteristic has several advantages in terms of building physics, but also has the effect that it allows moisture to penetrate constructions without a moisture control layer in wintery weather. Depending on the prevailing conditions, this may be as much as 100-150 grams per square meter (g/m^2) per day.

Structural damage due to condensation may result if the moisture that penetrates is unable to dry out again at the same rate.

If we look exclusively at the vapour diffusion flow, the moisture balance within the building components depends only on the local climate.

As explained before the diffusion flow is driven by the different climatic conditions inside and outside the building and therefore it is dependent on the climate at the location of the building.

Colder locations and locations with short summers are more critical when it comes to the moisture balance in winter. Warm locations and locations with long, humid summers are more critical when it comes to the moisture balance in the summer. In a Tasmanian location (e.g. Launceston or Hobart) the condensation in winter is more critical than in Queensland (e.g. Brisbane) and, conversely, indoor condensation in the summer is more critical in Queensland.

We have to keep constructions dry. Therefore a vapour barrier is beneficial in winter conditions, but it can cause problems in summer conditions, as the direction of diffusion flow can be reversed in the summer. The problem in summer is not necessarily the amount of water vapour, but rather the critical combination of moisture and heat absorbed into the outer material layers of the construction

forcing water vapour diffusion backwards and condensation onto the cooler inner vapour barrier.
Formation of condensation in the winter on the cold outer surface results in mould far less frequently and far more slowly due to the lower temperatures (comparable to the lower risk of mould in a fridge when it is on). In the summer, on the other hand, the conditions are almost ideal for mould to grow due to the high humidity and high temperature. Summer condensation is therefore extremely critical, in terms of a healthy living environment.

2.2 Moisture transport: Vapour convection

Convection is the transport of moisture vapour dissolved in the air, dependent on temperature and relative humidity. In contrast to the molecular transport of diffusion, the moisture bound in the air volume has an effect here.
A significantly larger amount of moisture is transported into the building envelope by air passing through gaps and penetrations in the inner airtight sealing layer ("vapour convection") rather than by diffusion through the airtight material itself. The Fraunhofer Institute for Building Physics in Germany conducted an investigation and various studies into the effects of gaps in the airtightness layer in 1989. [31]
They measured the flow of moisture resulting from gaps of various widths and pressure differences at an indoor temperature of 20 °C and an outdoor temperature of 0 °C. They found the amount of moisture transported into the construction by convection to be 1,600 times more than is transported by diffusion. The structure not only displayed an extreme increase in the amount of moisture, but also a significant deterioration of their thermal insulation performance. These alarming findings led to Germany becoming the first country in the world to make airtightness of the building envelope a legal requirement in 1995.
The pilot setup was first tested with perfect airtightness, see Figure 2.3. The moisture transport due to diffusion was negligible, at just 0.5 g/m² per day. A gap 1 millimetre (mm) in width and 1 meter (m) in length, at an outdoor temperature of 0 °C and with a pressure difference of 20 pascal (Pa) (which corresponds approximately to wind force 2-3, beaufort scale) allowed some 800 g/m of water into the construction per day via air flow (vapour convection) and wider gaps allowed even more in, see Figure 2.4.
Such quantities of moisture rapidly lead to the formation of condensation in all kinds of thermally insulated constructions, even on vapour permeable wall wraps. In building envelopes that are not thermally insulated, such as those to be found amongst Australia's old housing stock (e.g., state houses dating from 1930-1970), the moisture is carried out on the air flow unhindered, not halted by any thermal insulation or wall lining membrane. The air exchange rate (n_{50} value) of these old buildings was found to be as high as 64.7 air changes per hour, see Figure 2.5. [32] The upside of this is that it generally prevents condensation from forming. The downside, however, is the inadequate thermal insulation of the construction and the resulting poor quality living environment.
The measurements performed by the Fraunhofer Institute [26] were subsequently re-evaluated and confirmed by Prof. Pohl (University of Hannover, Germany) [33] and other researchers. This led to a rethink and ultimately had an effect on building regulations (standards), laws (e.g. thermal insulation regulations) and the building standards (practical construction work).
Vapour convection poses an immense risk of formation of condensation in all thermally insulated constructions, both in externally diffusion-open materials, but even more in externally diffusion-inhibiting materials. This is why building envelopes that are not airtight, but allow air flow through, are very susceptible to structural damage.
The construction methods common in Australia pose the risk that the vapour convection flow may cool on passing through the thermal insulation and form condensation on the outer surface of the insulation adjacent to the weatherproofing membranes.
From the above, it can be concluded that internal airtightness layers are an absolute necessity for healthy living. [see Preface] It is therefore advisable to measure the quality of the airtightness by means of a test, the Blower Door test. For further information, see the section on airtightness testing in chapter 8.0 "Quality assurance".

2.3 Moisture transport: Energy and moisture gap

As described before, air and vapour convection leads to the greatest moisture transport. A distinction is made between different paths on the basis of their flow path. This can be short or long and leads to the subdi-

Moisture transports into the construction due to penetrations in the airtightness layer

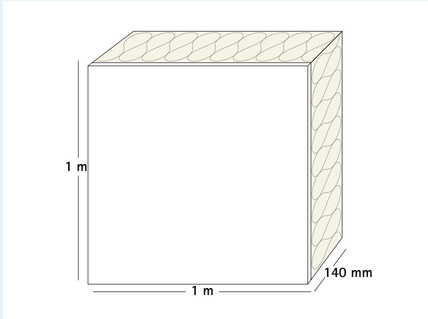


Figure 2.3: Moisture transport due to diffusion in winter, at a MVT-rate of 150 MNs/g, Moisture transport in winter due to diffusion: 0.5 g/m² x 24 h

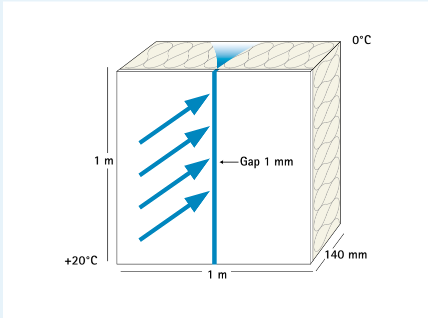


Figure 2.4: Amount of moisture due to convection, moisture transport, with a 1 mm gap: 800 g/m x 24 h,
Increased by a factor of: 1,600
Conditions:
Vapour retarder s_d value = 30 m (150 MNs/g)
Indoor temperature = +20°C
Outdoor temperature = 0°C
Pressure difference = 20 Pa corresponds to wind force 2 – 3
Measurement carried out by: Fraunhofer Institute for Building Physics, Stuttgart

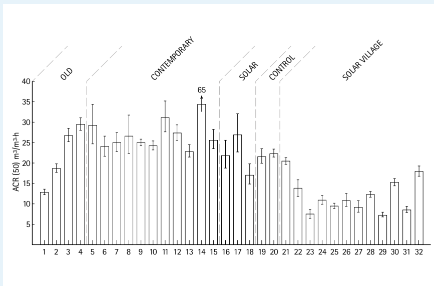


Figure 2.5: Air exchange rate (n_{50} value) of buildings, estimated values and 95 % confidence intervals of the permeability parameter ACR(50) for the houses tested.

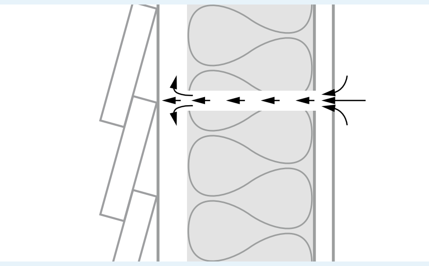


Figure 2.6: Energy leak

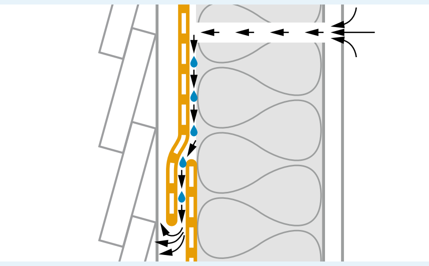


Figure 2.7: Moisture leak

If the timber dries by:

1 % is	100 g/m² water is released
10 % is	1,000 g/m² water is released
20 % is	2,000 g/m² water is released

Table 2.2: Humidity of the wood in a wood stand wall/m²
Dimensions: 4" x 2" (90 mm x 45 mm)
Timber length/m²: Studs 2.5, dwangs 2.5, total = 5 m
Timber weight/m² wall surface area:
90 mm x 45 mm and 5 m long ~ 0.022 m³/m²
0.022 m³/m² x 450 kg/m³ ~ 10 kg/m² i.e.
1 % drying = 100 g/m² water released

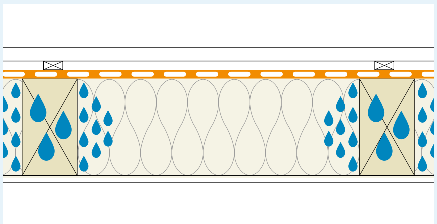


Figure 2.8: Damp building materials
Building materials that are installed damp or that become wet or damp during construction have to be able to dry out without damaging the structure. The amount of moisture this involves is often underestimated.

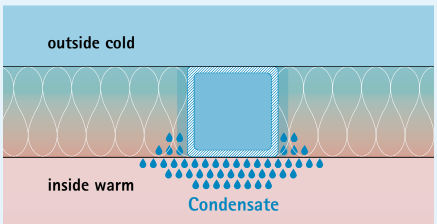


Figure 2.9: Damp due to thermal bridges
Thermal bridges contribute significantly to the growth of mould on the surfaces of building materials and to a reduction in energy efficiency.

vision into energetic and moisture leakages. A short, direct flow path through a structure leads more to energetic losses. A long flow path is more likely to lead to moisture accumulation.
In chapter 1.13.1 "During cooling: humidification, condensation, dew point" the mechanism of condensation is shown: If the moisture content of the air is round about at 100 % RH condensation will occur. In the outside air in autumn or winter, fog can be formed. Inside there will be no fog, but when heavily moisture loaded air hits an obstacle (such as a cold mirror in the bathroom), the water vapour in the air condenses.
Energy Gap (short, direct flow path): In the past, houses were built without thermal insulation. On the outside of the supporting structure was the external cladding and on the inside of the supporting structure was the internal lining. The cavity was without insulation. The inside air entered the structure in winter through the joints in the inner cladding, cooled down in the cavity with the effect of an extreme rising of the relative humidity. The heavily humidity loaded air flowed outside and escaped through the joints in the outer cladding. Since there were no obstructions (no thermal insulation) it had a high air velocity, see Figure 2.6.
The moisture could not condense even though the outer cladding was cold from the surface. The construction was free from mould.
When people realised that living in such constructions was like living in a tent they were eager to achieve a more comfortable indoor climate and save energy. To achieve this, the cavity was filled with thermal insulation material which leads us to moisture gaps.
Moisture Gap (long flow path): The warm interior air entering the construction through the gaps has got a good chance to cool down because of its slow air speed through the insulation material. In this process the water vapour condenses out, partly on the fibres of the insulation but mostly on the cold exterior cladding. Mould and decay can form, see Figure 2.7.
To cope with moisture and energy gaps, the installation of an airtight layer is essential. The interior cladding is not made to protect against air movement, because of the joints on the adjacent building components, because of installations, such as sockets and pipes, built-in parts, etc.. There are still the joints on the inside with the air entering and joints on the outside with the air leaving. See also chapter 3 for the development of the building standard in Australia.
It is absolutely necessary to prevent air infiltration, condensation and mould. A proper air sealing layer is needed on the warm side of the construction, ideally with an intelligent diffusion function.

2.4 Moisture source: Damp building materials

In addition to the effects of diffusion and convection flow, moisture can also be trapped in the construction by encapsulating wet materials within the construction phase. The amount of moisture held in the building materials during construction is often underestimated. If the timber frame gets wet due to rain during construction the wood becomes damp. This moisture needs to dry out again to prevent mould from forming, see Figure 2.8.
The proportion of timber in walls is typically quite high in Australia.
At a grid dimension of 450 mm, about 2.2 timber studs are needed per metre of wall, which corresponds to approx. 2.2 m of wood per m² of wall area. In addition, there are also the bottom plates, the trimming and frames for doors and windows as well as top plates. In total, it is safe to assume an additional length of 3 m of wood per m², amounting to 5.2 m per m². At a timber cross-section of 4" by 2" (90 mm x 45 mm), this results in a volume of 0.021 m³/m². At a density of 450 kg/m³ this amounts to approximately 9.5 kg of wood per m² of wall. In the building envelope, once it has been constructed, the wood dries out, i.e. its high initial moisture content is given off within the construction. If the wood has to dry by 10 %, e.g. from 30 % to 20 %, then moisture amounting to 10 % of the weight of the wood has to dry out. In the example given this is 10 % of 9.5 kg of wood per m² of wall, which corresponds to 950 g/m² of moisture, or ~1 litre, see Table 2.2.
This means that for a typical Australian wall: At a timber drying rate of 1 %, 95 g/m² of moisture is given off into the construction, and at a timber drying rate of 10 %, this rises to 950 g/m². This additional moisture needs to be able to escape to avoid structural damage. Thermal energy is required to dry the wood out.
In warmer climate regions and in summer, this thermal energy comes from outside. Then in typical Australian buildings, there is a risk of condensation forming on the cooler internal parts of the wall. In colder regions and in winter the thermal energy comes

from inside and there is a risk of condensation forming on the external surfaces of the building, which are now cold. It is thus necessary to ensure that the timber frame either stays as dry as possible (protection from the elements) and/or that the construction process allows time for the wood to dry out again. It is also necessary that the thermal insulation is not put in place until the wood has dried out.

2.5 Moisture source: Thermal bridges

Thermal bridges cause localised cold spots within the construction. If the surface temperature drops below the saturation temperature of the air there is a risk of increased humidity. Although thermal bridges do not directly cause moisture within the construction, they contribute significantly to the growth of mould on the surfaces of building materials and to a reduction in energy efficiency, see Figure 2.9. For further information, see chapter 9.0 "Thermal bridges".

2.6 Bad construction sequence

Another potential source of elevated moisture transport is a poorly coordinated construction sequence. Normally the construction of a building is first sealed from the outside with a flexible or rigid weather resistant barrier and then the insulation is put in place on the inside. If construction is poorly coordinated, it may take several weeks after that before the indoor airtightness membrane is installed. That is no problem in the summer, when the moisture travels from the outside to the inside. In the winter, however, this can lead to a significant increase in humidity, and thus to condensation, in the layer of the wall where the insulation is, especially in cooler regions such as in Canberra, Melbourne or Hobart. In the winter, the direction of diffusion is towards the outside and, due to the lack of a smart vapour control layer, the moisture can enter the insulated parts of the construction unhindered. This leads to the risk of condensation forming on flexible external weather resistive barriers, or rigid sheathing like plywood or fibre cement boards depends on the outward flow rate of the moisture and the diffusion tightness of the outer WRBs. In 2015 the building code introduced new weatherproofing requirements which are compounding the effect by driving more well sealed, airtight, watertight and weathertight WRB membranes.
Any accumulated moisture is usually not visible and goes unnoticed at the time when the airtightness layer or plasterboard is put into place. This results in a significantly higher risk of mould. When planning the construction sequence it is therefore necessary to make sure in cold climate conditions that the airtightness layer is sealed within a few days of putting the thermal insulation in place in order to protect the construction from additional moisture. Intelligent Air Barrier (IAB) systems using pro clima INTELLO® PLUS are the ideal solution.

2.7 Moisture transport: Driving rain

Moisture entering the building due to driving rain is commonly referred to as "leaky building syndrome". This is when driving rain penetrates the façade around poorly detailed fixtures such as windows and doors and enters the thermally insulated construction. In many parts of Australia, all the way along the east coast for instance, there is a lot of driving rain and predominantly where the population resides. Poor sealing is one of the possible reasons for damage to wall constructions, especially in high-risk regions. For damage to the timber frame to occur, moisture has to penetrate the wall wrap from the outside. It is therefore worth selecting a wall wrap that is very watertight (water column/head > 10,000 mm), and is also diffusion-open (non-porous membrane with diffusion-active moisture transport), see Figure 2.10.
Both poor airtightness and thermal bridges can result in the same symptoms and effects as leaky building syndrome. Both can allow a considerable amount of moisture to enter the construction from the inside and condense on the outside.
The moisture from the inside can be seen both outside and inside on all of the component layers, appearing as if it came from outside. This phenomenon is stronger on the leeward side of buildings due to the suction of the wind than on the windward side, allowing it to be distinguished from leaky house syndrome, see Figure 2.11.
If there is damage in the region of the corners of the building and fixtures such as windows and doors, it is also advisable to consider the risk of moisture from inside as well as the risk of water entering through leaks in the façade. This can occur on the one hand due to the lack of airtightness and on the other hand due to thermal bridges caused by a complete lack of or insufficient

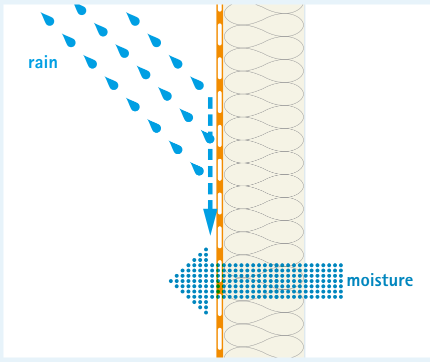


Figure 2.10: Damp due to driving rain
Ideal against water penetration from outside due to driving rain
- Façade sheeting that is very watertight, but simultaneously has a low diffusion resistance
- Watertight joints to all holes, penetrations and fittings such as windows and doors

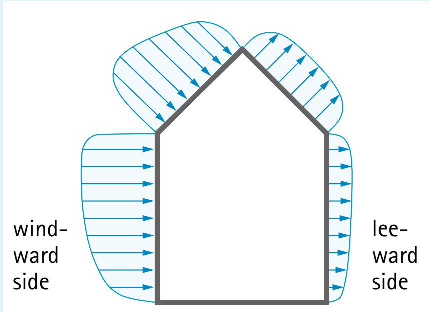


Figure 2.11: Wind effect

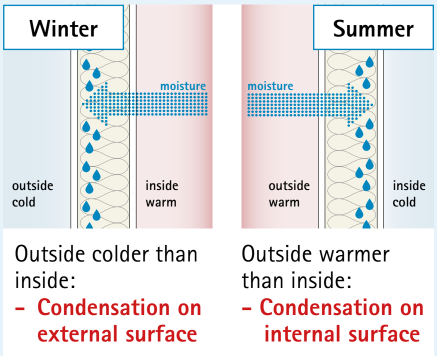


Figure 2.12: Diffusion flow in summer and winter

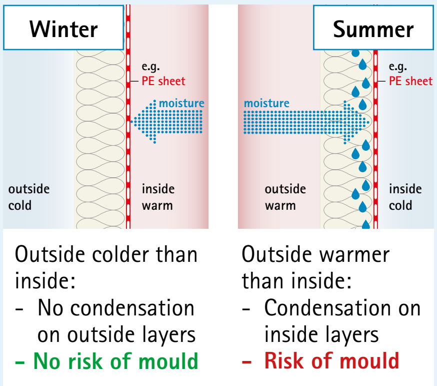


Figure 2.13: The effects of a vapour barrier on the inside

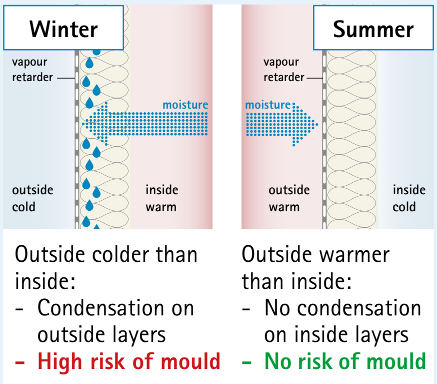


Figure 2.14: The effects of a vapour barrier on the outside. WBP (wood based panel)

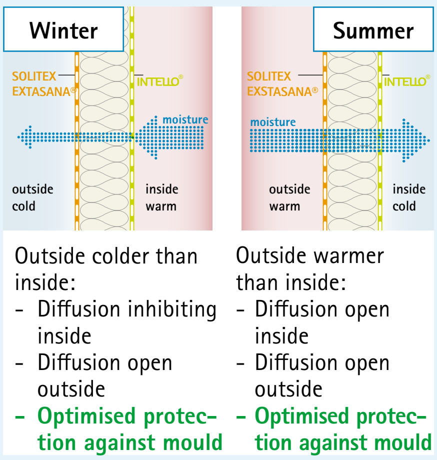


Figure 2.15: The effects of intelligent moisture management

thermal insulation in these areas. Both of these causes, poor airtightness and thermal bridges, result in a drop in temperature of the inner surfaces and thus promote the formation of condensation, both inside and outside. As described above, wind suction can cause condensation to form, especially on the downwind side (leeward side) by sucking air out of the building into the construction, even if the façade is not leaky.
When sealing fixtures in exterior walls such as doors and windows, the outer layer of flashing should be watertight. To prevent structural damage, it would be advisable to connect wall wrap, plywood or cement boards with windows and doors by using TESCON EXTORA®, TESCON EXTORA® PROFIL or CONTEGA® EXO tape to obtain a windtight layer that includes all fittings. In terms of achieving a permanently dry construction, the external sealing tape used should be diffusion-open, not impermeable. Diffusion-tight tape acts as a vapour barrier on the outside, which significantly increases the risk of condensation and thus of mould, especially for the moisture from inside, either by diffusion or convection flow. We hope the certification guidelines will be amended in Australia soon, so externally diffusion-open fitting details using adhesive tape will be adopted as standard for construction purposes.
Well protected constructions are well sealed on the outside WRB, while also being diffusion-open, and the same applies to joints.

2.8 Moisture transport: Ventilation systems

Ventilation systems may operate at a slight under pressure. In other words, the fan that sucks air out of the building moves slightly more air than the fan that blows air into the building. When this happens, the warm, moist indoor air penetrates the building's construction from within, then condenses causing mould to grow.
A ventilation system that operates at overpressure is able to pump warm, moist indoor air through penetrations (gaps) into the construction. This can increase the moisture transport in the winter, resulting in potential structural damage.
The opposite could happen with ventilation systems that operate at an under pressure in the summer & in warm humid regions, with warm air from outdoors being sucked into the building envelope. It is then possible for warm, moist outdoor air to enter the building envelope from outside and condense on cooler surfaces of material on the inside, increasing the risk of mould growth.
So, for buildings with a ventilation system it is not only the airtightness from inside that matters, but also the windtightness of the construction from outside that needs to be optimised, both in terms of planning and in practice.
In terms of freedom from structural damage, ventilation systems that adapt to the environmental conditions are ideal. These are those which operate at an overpressure if it is outside warmer than inside (if the water vapour partial pressure outside is higher than inside) and operates at an under pressure if it is colder outside than inside (if the water vapour partial pressure outside is lower than inside).

2.9 Intelligent control of diffusion flow

In the winter, the direction of diffusion flow is towards the outside. This means that condensation may occur on the cold surfaces of external parts of the building.
In the summer & in warm humid regions the direction of diffusion flow is reversed so it carries moisture inwards, which can result in condensation forming on the cooler surfaces of internal parts of the building, see Figure 2.12.
A high resistance membrane on the inside of the wall provides good protection against moisture penetrating the construction from inside in the winter. However, in the summer there is a risk of condensation forming on the internal vapour control layer, if the moisture is carried from outside inwards, see Figure 2.13.
A vapour barrier (high resistance) on the outside of the wall would provide good protection against moisture penetrating the construction from outside in the summer & in warm humid regions. However, in mixed climates in the winter there would be a risk of condensation forming on the vapour control layer, if the moisture were to be carried from inside to outside, see Figure 2.14.
The ideal solution therefore is to have a combination in the form of an intelligent airtightness membrane, which adjusts its diffusion resistance to the ambient conditions, see Figure 2.15.
Convective moisture transport is much more critical than moisture transport due to diffusion flow. A complete lack of or insufficient airtightness membrane in thermally insulated timber and steel structures leads to very

high moisture levels due to convection flow in the winter, usually resulting in structural damage. [34]

An intelligent airtightness membrane may be simply expressed as an Intelligent Air Barrier (IAB) and needs to form part of an intelligent airtightness system. This includes accessories such as durable tapes required for the junctions and joints in the Intelligent Air Barrier to maintain continuity of the airtight layer.

The ideal solution is to have on the inside Intelligent Air Barrier system with a higher diffusion resistance (diffusion-inhibiting) in the winter and with a lower diffusion resistance (diffusion-open) in the summer, see Figure 2.16. This is achieved by pro clima INTELLO® PLUS, an Intelligent Air Barrier membrane with humidity-variable diffusion resistance.

Its diffusion resistance varies automatically, depending on the ambient climate conditions, so it always has the ideal diffusion resistance. This function is governed by the average ambient humidity surrounding the membrane. As soon as the average ambient humidity surrounding the membrane rises, it becomes more diffusion-open, but if the average ambient humidity surrounding it drops, its diffusion resistance increases.

The average ambient humidity surrounding the membrane depends on the ambient environmental conditions.

If it is warmer indoors than outdoors (winter), moisture travels from inside outwards, so the airtightness membrane is in a dry environment (low relative humidity indoors and in the adjoining building elements).

If it is colder indoors than outdoors (summer), moisture travels from the outside inwards, so the airtightness membrane is in a damp environment (high relative humidity indoors and in the adjoining building elements).

The environment governs the relative humidity surrounding the membrane – and the relative humidity governs the diffusion resistance. Alternating vapour flow direction takes place between summer and winter, but also between night and day. The average ambient humidity of the airtightness membrane due to moisture transport from inside to outside is approximately 30 % RH in timber and steel frame structures in wintery weather, see Figure 2.17 and Table 2.3.

In warmer weather, on the other hand, the relative humidity surrounding the membrane is higher due to the reversal of the direction of diffusion flow if there is moisture in the construction. This can result in summer

Moisture situation in the construction

The vapour diffusion flow is always from the warm side to the cold side. Thus:

- In the winter: Condensation risk on the outside
- In the summer: Condensation risk on the inside

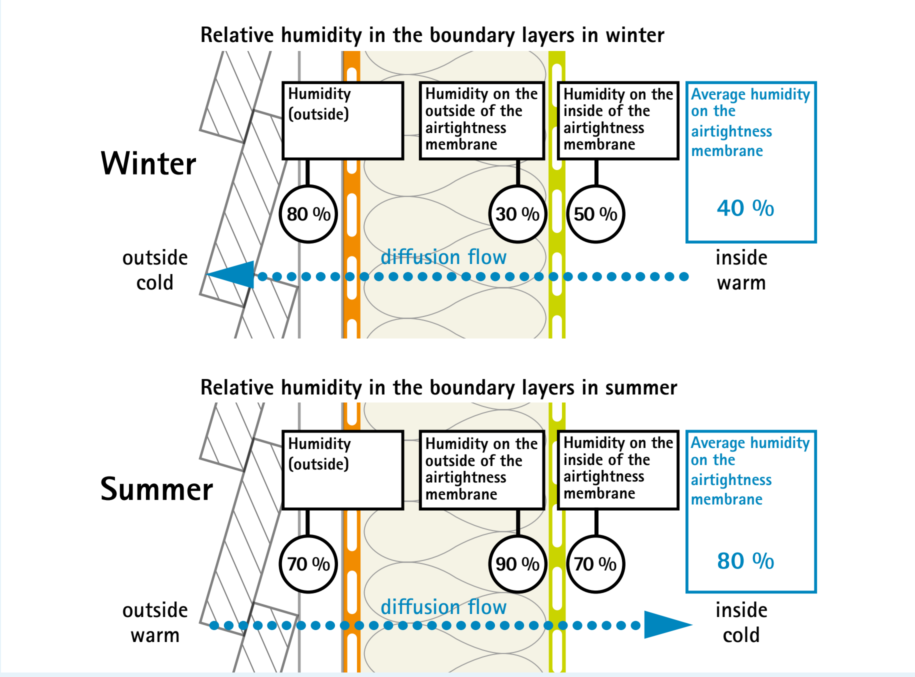


Figure 2.16: Schematic diagram of the relative humidities surrounding the vapour retarder/airtightness membrane in winter and summer
In the winter, the airtightness membrane is surrounded by low humidity:
- The humidity-variable airtightness membrane is more diffusion-inhibiting
In the summer, the airtightness membrane is surrounded by high humidity:
- The humidity-variable airtightness membrane is more diffusion-open

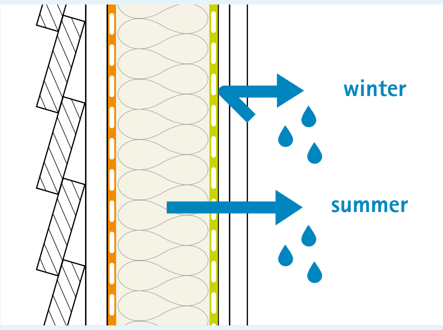


Figure 2.17: The operating principle of an air barrier membrane with humidity controlled vapour diffusion resistance
Humidity controlled airtightness membrane is diffusion-inhibiting in the winter, protecting the construction from condensation, but is able to become diffusion-open in the summer, allowing the construction to dry out

Diffusion flow	Moisture flow rate in g/m² per week	
	In the winter	In the summer
Direction of diffusion flow	Outwards, towards the roof underlay, wall wrap	Inwards, towards the airtightness membrane
INTELLO® PLUS	7	560

Table 2.3: Diffusion flow through the pro clima INTELLO® PLUS humidity-variable airtightness membrane

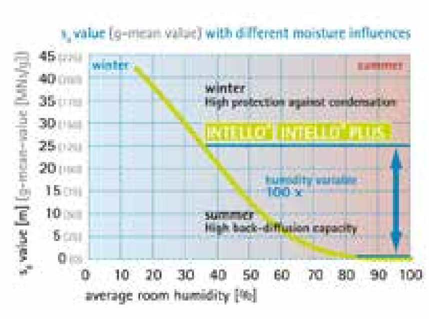


Figure 2.18: Vapour diffusion resistance characteristics: pro clima INTELLO® PLUS airtightness membrane: High humidity variability

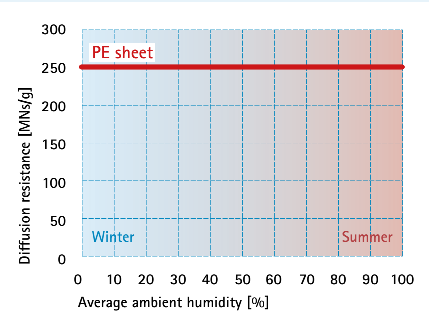


Figure 2.19: Vapour diffusion resistance characteristics: Vapour barrier PE sheet: No humidity variability

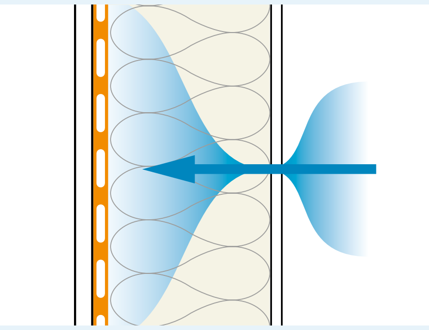


Figure 2.20: Moisture transport due to convection through gaps in the inner lining. A significant amount of moisture can penetrate the building envelope by convection. This poses the risk of structural damage and mould if there is insufficient moisture compensation. The ideal solution is intelligent moisture management.

Figure 2.21: Moisture damage and wood rot on the outside (cold side) of the stud work behind the WRB. [35]

condensation if vapour barriers and vapour retarders with constant diffusion resistance are used on the inside.

The diffusion resistance of pro clima INTELLO® PLUS, which is over 125 MNs/g in the winter, can drop to as low as 1.25 MNs/g in the summer, see Figure 2.18.

Vapour barriers such as polyethylene (PE) sheet or aluminium foil, on the other hand, have a constant diffusion resistance. In other words, they have the same diffusion resistance in the winter (dry) as in the summer (damp), which means they can rapidly become moisture traps, see Figure 2.19.

Since 1991, pro clima Intelligent Air Barrier systems have proven themselves worldwide, with millions of m² having been installed. INTELLO® PLUS is a membrane developed to cover an especially broad diffusion resistance range that is effective in every climate. Its humidity-variable diffusion resistance ranges from 1.25 MNs/g to over 125 MNs/g.

A humidity-variable membrane needs to have a diffusion profile that is also suitable for preventing structural damage in wet/humid rooms that have increased relative humidity levels. The increase is due to occupancy-generated moisture. The same applies to the higher initial moisture content in new buildings. the specifications are defined by the drying period of new buildings (60/10 rule) and the hydrosafe-value (70/7.5 rule) described in chapter 10.0. "Notes on planning and construction".

2.10 Summary

As discussed, it is impossible to provide 100% protection against moisture for any construction. It is therefore necessary to choose a construction and building materials that are able to cope with moisture. In principle, this means systems that are open to diffusion to the outside. The ideal solution is to use sealing systems that automatically adapt to the environmental requirements.

Use of vapour retarders with a constant diffusion resistance can cause condensation on the indoor surfaces of building materials in the summer ("sweating"). This results in a very high risk of mould due to the combination of moisture and temperature.

Moisture due to diffusion can be allowed for. The intelligent moisture management membrane pro clima INTELLO® PLUS provides optimum protection against structural damage and mould due to its variable diffusion resistance. This is diffusion-inhibiting in the winter, and open to diffusion in the summer.

Convective moisture transport is much more critical than moisture transport due to diffusion.

A complete lack of, or insufficient airtightness membrane in thermally insulated timber and steel frame construction leads to very high moisture levels due to convection in the winter. Usually resulting in structural damage, see Figure 2.21.

The timber used for the structure should be dry when the thermal insulation is installed and the airtightness layer put in place.

On one hand, the objective is to plan and integrate an airtight and moisture-regulating layer in all constructions. On the other hand the objective is to increase the drying capacity of the building envelope. The potential freedom from structural damage should be as high as possible. Both of these requirements are fulfilled by pro clima's Intelligent Air Barrier membrane INTELLO® PLUS.

Intelligent moisture management system protection formula:

Drying capacity > moisture load = freedom from **structural** damage

Only if the moisture that enters the building envelope (plannable and unforeseen) is able to dry out quickly and completely can the construction remain free of structural damage.

3. This is Australia

I love a sunburnt country,
A land of sweeping plains,
Of ragged mountain ranges,
Of droughts and flooding rains.
I love her far horizons,
I love her jewel sea,
Her beauty and her terror –
The wide brown land for me!
"My Country" by Dorothea Mackellar

Often perceived as a dry country, Australia's climate is actually difficult to broadly characterise. The climate in the regions varies from very cold and wet to very hot and dry to very hot and wet. This presents specific challenges for consistency to standard building approaches that will work across the entire country to produce healthy, durable and energy efficient buildings.
In respect to broad regional construction type differences the main noticeable variances are between the east coast and west coast which are separated by vast dry deserts and sparsely populated areas, east coast residential construction is dominated by brick veneer and the west coast by cavity brick construction.

3.1 Rainfall – exterior moisture

The east coast weather patterns are largely influenced by the Great Dividing Range which extends from Victoria all the way up to Far North Queensland causing a concentration of rainfall along the east coast. Typically, cooler weather is experienced in the higher altitude regions behind the coastal regions. The Pacific Ocean provides a large source of moisture which feeds the winds with moisture and the orographic uplift from the Great Dividing Range forces the moisture back to the ground as rain. This creates pockets of high precipitation scattered up the New South Wales and Queensland coastline. The temperature and humidity varies greatly from the temperate regions at the Victorian boarder to the tropical rainforests of Queensland.
Rainfall tends to be concentrated along the east coast of Australia, particularly in tropical north Queensland. Cold ocean currents off the coast of Western Australia result in little evaporation occurring. Hence, rain clouds are sparsely formed and rarely do they form long enough for a continuous period of rain to be recorded. Australia's arid/semi-arid zone extends to this region. The absence of any significant mountain range or area of substantial height above sea level, results in very little rainfall caused by mountain uplift. In the east the Great Dividing Range limits rain moving into inland Australia, see Figure 3.1.

3.2 Hygrothermal design for climate – Australian climate zones

The eight climate zones defined by the National Construction Code (NCC) are used as a basis for selection of tests cases in this study. Each climate zone has distinctly different issues for managing external rain and outdoor moisture laden air versus indoor humidity issues. The interior or exterior risks are based on the dominance of heating or cooling in each climate and the resulting potential for moisture accumulation in the internal or external layers of the construction. Within each main zone there are many regional sub-zones determined by local geographic features including wind patterns and height above sea level. Within this study the general NCC climatic regions are taken into consideration, see Figure 3.2.

3.2.1 Climate zone 8: Alpine

Main characteristics:
The alpine regions of Australia are the least populated areas characterised by low humidity, high daily temperature range with four distinct seasons: winter exceeds human comfort range, cold to very cold winters providing majority of rainfall and some snow. Warm to hot, dry summers; highly variable spring and autumn conditions are experienced.
Key hygrothermal design objectives:
The main focus is allow moisture to escape from the external side of the construction and preventing internal water vapour from entering the construction using properly implemented Intelligent Air Barriers (IAB).
This zone is excluded from the study because there are no meteorological stations to generate suitable climate files for WUFI®. Buildings are to be specified with construction features same as for zone 7, see Figure 3.3.

3.2.2 Climate zone 7: Cool temperate

Main characteristics:
This climate is now moving into the most well populated "coolest" region of Australia. Low humidity, high daily temperature range, four distinct seasons: summer and

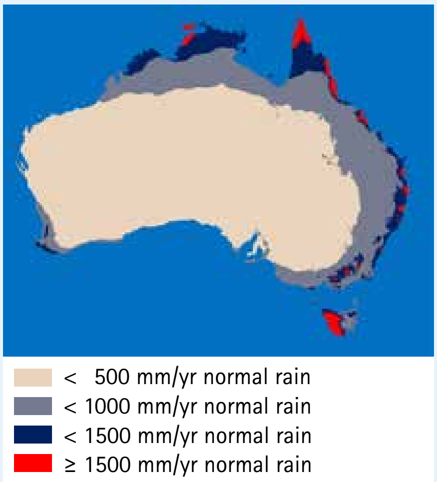


Figure 3.1: Rainfall distribution across; Australia; Low, Medium, High and Extreme. [36]
Hygrothermal design requires that insulation systems, water tight and wind tight Weather Resistive Barriers (WRB) and internal Intelligent Air Barrier (IAB) systems with smart vapour control are selected appropriately based on the climate and risk of rainwater penetration. Drainage and ventilation in cavities provides a function of liquid water removal and drying of residual wetness based on the overall geographical risk of external rainwater ingress.

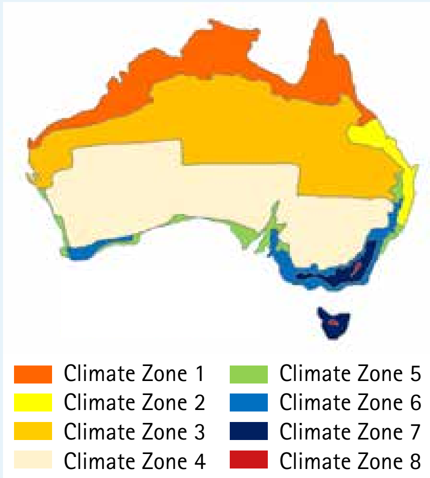


Figure 3.2: Building Code of Australia (BCA) climate regions [37]

Figure 3.3: BCA climate zone 8

Figure 3.4: BCA climate zone 7

Figure 3.5: BCA climate zone 6

Figure 3.6: BCA climate zone 5

winter exceed human comfort range; highly variable spring and autumn conditions. Cold to very cold winters with majority of rainfall. Hot dry summers.

Key hygrothermal design objectives:

The dominant vapour drive in this region will be from inside to outside. The construction systems will need to incorporate Weather Resistive Barriers (WRB) that encourage outward drying and internal Intelligent Air Barriers (IAB) to limit internal moisture from entering the construction. Inward vapour drive may be an issue under solar driven reverse vapour drive on north, east or west facades, see Figure 3.4.

Reference Cities:

Canberra
Hobart

3.2.3 Climate zone 6: Mild temperate

Main characteristics:

Low daily temperature range near coast with a high daily swing inland. This climate is characterised by four distinct seasons: summer and winter exceed human comfort range and will require some form of heating and cooling; spring and autumn are ideal for human comfort. Mild to cool winters with low humidity, with hot to very hot summers and moderate humidity.

Key hygrothermal design objectives:

Due to the cooler winters climate zone 6 is generally considered a "cool" climate in the context of Australia. However, this climate does get really hot in summer which presents the same design challenges with reversal of seasonal vapour drive as climate zone 5. Inland regions have daily temperature swings which are large enough to reverse the direction of vapour flow on a daily basis. This means that the construction needs to be able to manage outward moisture movement and inward moisture movement on a daily and/or seasonal basis maximising the overall annual drying potential of the construction, see Figure 3.5.

Reference City:

Melbourne

3.2.4 Climate zone 5: Warm temperate

Main characteristics:

Moderate diurnal (day–night) temperature range near coast to high diurnal range inland. This climate region has four distinct seasons: summer and winter can exceed human comfort range and will require some form of heating and cooling; spring and autumn are ideal for human comfort and this is one of the most populated climate regions in Australia.

It is characterised by mild winters with low humidity, hot to very hot summers with low to moderate humidity and widely variable sunshine and wind directions and patterns.

Key hygrothermal design objectives:

The vapour control layer should go on the warm side of the insulation! Here lies a problem. Which one is the warm side? This climate has a warm side which swings depending on the season. This means that the construction needs to be able to manage outward moisture movement in winter and inward moisture movement in summer maximising the overall annual drying potential of the construction, see Figure 3.6.

Reference Cities:

Perth
Sydney
Adelaide

3.2.5 Climate zone 4: Hot dry summer, cool winter

Distinct seasons with low humidity all year round, high daily temperature range and low rainfall. Very hot summers common with hot, dry winds and cool winters with cold dry winds.

Key hygrothermal design objectives:

Due to the windy nature in summer and winter this makes air sealing essential in this region. When buildings are either being heated or cooled the effects of the wind need to be managed through appropriate control layers. The exterior WRBs are wind control layers and interior Intelligent Air Barriers (IAB) mitigate the effects of these strong winds on the energy consumption. Although the outdoor conditions are dry all year more airtight buildings mean that the internally generated moisture still needs to be managed appropriately. Very cool night time temperatures that may be experienced can be dealt with by appropriate outward drying potential, see Figure 3.7.

Reference City:

Mildura

3.2.6 Climate zone 3: Hot dry summer, warm winter

Inland regions in the northern part of Australia have distinct wet and dry seasons, Low rainfall and low to moderate humidity. No extreme cold but can be cool in winter. Hot to very hot summers are common and clear night skies can create significant diurnal (day–night) temperature ranges.

Key hygrothermal design objectives:
This climate is characterised by low humidity levels. Which for hygrothermal design allows for an easy way to utilise exterior air to remove moisture from construction systems at a high rate. Fundamental to homes that make efficient use of air conditioning is to have an air sealed structure in this climate, this in itself can result in elevated moisture in the living space. Extremely cool nighttime temperatures that may be experienced can be dealt with by appropriate vapour permeable layers with outward drying capacity, see Figure 3.8.
Reference City:
Alice Springs

3.2.7 Climate zone 2: Warm humid summer, mild winter

The coastal region of South-East Queensland and northern New South Wales coastline is a densely populated region experiencing high humidity with a definite "dry season", and hot to very hot summers with mild winters. Distinct summer and winter seasons are experienced and moderate to low daily temperature range is experienced. This can vary significantly between regions (e.g. inland to coastal) with increasing altitude of the Great Dividing Range. The mountains induce rainfall along the coastline producing some of the highest annual rainfall in the whole of Australia.
Key hygrothermal design objectives:
In air-conditioned buildings in these regions construction system orientation is crucial to the direction in which water vapour is driven. The cladding type, the amount of moisture storage capacity within the cladding and the solar exposure of the wall are critical to selecting the correct layers to prevent long term issue on the external or internal side of the construction, see Figure 3.9.
Reference City:
Brisbane

3.2.8 Climate zone 1: Hot humid summer, warm winter

The tropical climate region in Australia is characterised by high humidity with a degree of "dry season", it has moderate to high temperatures year-round and low to moderate seasonal temperature variation. It generally has very minimal daily temperature swing between day time and night-time.
Key hygrothermal design objectives:
This climate has unique and challenging design requirements for air-conditioned buildings in this region because of the climate conditions – extreme temperature, humidity, rain, wind/cyclones. For air-conditioned buildings a high level of airtightness is required due to extreme vapour pressure on the outside of the building coupled with humidity control indoors.
The temperature difference in zone 1 is always from the warmer outside to the colder inside conditions. This requires different performance and construction layer specification compared to cooler regions. From building physics point of view the airtightness layer must be placed in zone 1 on the warm side of the constuction, i.e. on the outside not like in zone 2 to 8 on the inside of the construction. This leads to different solutions for state of art in zone 1 compared to zone 2 to 8.
Of paramount importance in the wet tropics is exterior weathertightness. In order to achieve this, airtightness on the exterior not only manages water vapour but contributes considerably to achieving an extremely watertight strucutre in these extremely windy and rainy climates, see Figure 3.10.
Reference City:
Darwin

3.3 How we got there!

3.3.1 The emergence of foils

In the early 1900s "sarking type materials" were used behind cladding materials to help manage external moisture ingress. This building paper itself allowed water vapour to pass and drying to occur, but added no insulative value to the structure. It was not until the 1940's that one of Australia's largest building paper manufacturers innovated and added aluminium foil laminated to their products. This then allowed thermal resistance to be attributed to the air layer adjacent the foil, but also converted the properties of their products into vapour barriers.
In a 1954 Research paper, "The Thermal Insulating Value of Airspaces", Robinson and Powlitch popularised the use of low emittance surfaces to reduce heat flow through construction through a methodology that allowed R-values to be calculated for air spaces abonded by air gaps up to 89 mm (the thickness of a stud wall). However these values only "apply to airspaces of uniform thickness, with reasonably flat surfaces of moderate smoothness, and with no air leakage of air into or out of the space, or between spaces where two spaces are used." [38]


Figure 3.7: BCA climate zone 4


Figure 3.8: BCA climate zone 3


Figure 3.9: BCA climate zone 2


Figure 3.10: BCA climate zone 1

Hygrothermal situation and consequences

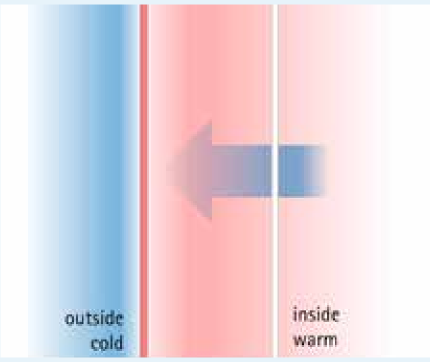


Figure 3.11: Pre 2005 energy efficiency: Foil membrane only, 90 mm stud bay, 10 mm plasterboard

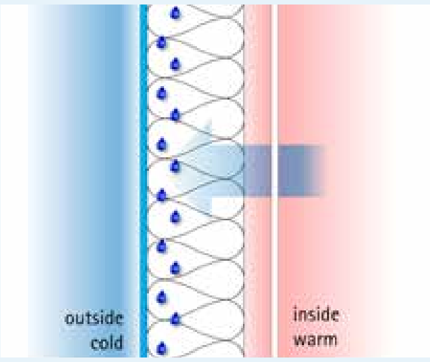


Figure 3.12: Post 2005 energy efficiency: with R1,5 (75 mm) or 2.0 (90 mm) fibrous insulation
Layers: Foil, 75 mm Fibrous Insulation, 10 mm plasterboard

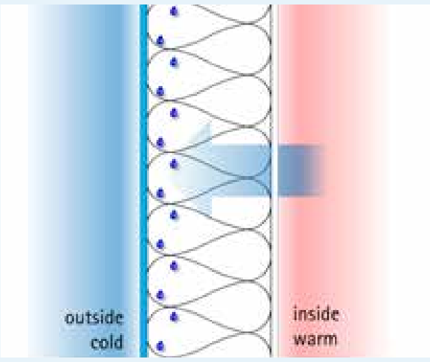


Figure 3.13: Post 2016 Energy Efficiency: with R2.5 (90 mm) or 2.7 (90 mm) Fibrous Insulation
Layers: foil, 90 mm Fibrous Insulation, 10 mm plasterboard. Mould and decay in these situations were not a matter of poor workmanship but the consequence of a system error.

Important Note: Increasing insulation to fully fill cavities reduces the risk of condensation due to the added vapour resistance of the thicker insulation and added moisture buffering. Taking this to the extreme, in theory several meters thick insulation in walls could completely solve the condensation issue. However this is impractical and cost prohibitive and alternatively vapour control layers on the inside need to be investigated for typical and cost effective wall (and roof) thicknesses.

3.3.2 The emergence of fibrous insulation

The national construction code represents the worst possible building you are legally allowed to build. In 2003 the energy efficiency provisions for the building code were introduced. This led to the widespread uptake of fibrous insulation in housing to reduce the amount of energy required to heat and cool.
The combination of highly permeable insulation types in conjunction with a high vapour barrier on the outside of the insulation then creates the perfect condensation trap as shown in Figure 3.12.

3.3.3 Increasing energy efficiency

The now called National Construction Code for residential energy efficiency allows the National House Energy Rating Scheme (NatHERS) as a method of compliance. This star rating system is based on a calculation of the amount of heating and cooling required to keep a home comfortable under a standard set of assumptions. What originally started in 2003 as 4 Stars minimum, has progressively and incrementally increased since 2003. This has resulted in thicker fibrous insulation used in conjunction with aluminium foils.
Interestingly as small amounts of insulation are added the condensation risk increases drastically. But adding thicker insulation makes the situation slightly better as in Figure 3.12 & 3.13.
As of November 2011, 6-Star equivalence is the current minimum requirement in most of Australia. In recent updates the NCC has now moved to 7 star requirments. This progress has generally driven up the use of fibrous insulation in the structural framing of housing. NSW is not linked to star ratings but has driven the increased use of insulation through a seperate rating tool, the Building Sustainability Index (BASIX), a similar trend in incremental increases to higher performance has occurred. The vapour barriers were not necessarily a problem, because of both:

- The aluminium foil remained warm and on these warm surfaces there was no condensation, Figure 3.11.
- If there was any condensation, there was a high air flow because the aluminium foil was not sealed like an air barrier.

This changed with the emergence of fibrous insulation types used within stud bays adjacent to the foils. If heat is retained on the indoor side, for every action there is an equal and opposite reaction, this means the outermost layer (aluminium foil) gets colder. This creates "unintended consequences" of energy efficiency manifesting in condensation, see Figure 3.12.
The vapour barriers were then a problem, because of both

- The aluminium foil was cold and on cold surfaces there was high condensation of the moisture entering from the inside supported by the lack of internal air and vapour control layers.
- Condensation is not able to evaporate, because the fibrous structure reduced and hindered an air flow. See chapter energy and moisture gap chapter 2.3.

3.3.4 Addicted to foil

It was not until 1994 that the original 1954 research embedded itself in Australian folklore when it made its way into Australian Standards. [39] These standards are still used today to claim R-values at the expense of a high risk of condensation, mould & perverse health impacts on occupants.

3.3.5 Kicking the addiction

In 2011, a 6 Star performance was introduced, resulting in increased insulation levels another notch. In the same year the Australian Buildings Codes Board released the first version of the condensation handbook in an attempt to mitigate emerging problems.
"The information contained in the Handbook has been developed in order to provide additional information, detail and advice relating to the management of the risk of condensation in buildings, particularly the interstitial spaces within the roof and walls of framed buildings. The presence of condensation, particularly within the concealed voids of buildings gives rise to infestations of fungus and mould which have the potential to be injurious to the health of occupiers, and, which can accelerate the deterioration of building materials including structural components." [40]
In 2014 the second edition of the handbook was released.
"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." [41]

In 2015 the National Construction Code introduced a verification method including large scale weather testing of façade systems to AS/NZS 4284. Cladding systems tested to this standard constitute best practice weatherproofing systems normally incorporating a flexible or rigid Weather Resistive Barrier (WRB) (Figure 3.14 & 3.15).

In this standard it is necessary to not only pass the spray rack testing at the designated pressure but also a key performance parameter is to meet minimum air leakage threshold through the façade system which is set at 1.6 L/s/m² at ±150 Pa. By virtue of weatherproofing requirements, a watertight WRB system is an airtight WRB system.

State of the art waterproofing in Australia is therefore leading us to tighter buildings. The very systems that are designed to stop liquid water entering the building may be the systems that trap water vapour behind the WRB as our buildings get tighter and more weatherproof.

In 2016 a scoping study for condensation in residential buildings was undertaken, commissioned by the ABCB, Dewsbury et al found "The extent of the problem may include 40 % of all Class 1 and Class 2 buildings." [42] www.proclima.com.au/abcb-condensation

In 2018 the "Parliament of the Commonwealth of Australia" released a report on the inquiry into biotoxin related illness in Australia.

"The Committee received evidence that buildings that have been exposed to water damage (and subsequently experienced high levels of mould and dampness) may contribute to ill health in susceptible individuals. Health effects described by inquiry participants were varied, often debilitating, and included cognitive and physical symptoms." [43] www.proclima.com.au/biotoxin

In addition the Building Confidence Report was damning of the construction industry and moisture management: "We have read numerous reports which identify the prevalence of serious compliance failures in recently constructed buildings. These include non-compliant cladding, water ingress leading to mould and structural compromise, ..." [44]
www.proclima.com.au/building-confidence

In 2019 Deakin university analysed 212 building audit reports consisting of 3227 defects across New South Wales, Queensland and Victoria. This is on average about 15 defects per building where it was found that: "40.19 % (n=1297) of the defects identified in the reports were categorised to building fabric and cladding, followed by fire protection (13.26 %, n=428), water proofing (11.46 %, n=370)." [45] (Figure 3.16)
www.proclima.com.au/deakin

3.3.6 Acknowledging the issue

In 2019, the ABCB Condensation handbook was updated to new condensation requirements introduced in the NCC 2019 which established vapour permeable membranes on the external side of insulation in climate zones 6, 7 and 8 to help resolve emerging issues.

However, even the ABCB acknowledges that the new measures "aren't a magic bullet. You can follow the NCC and may not prevent condensation in all cases. You can still get condensation if you follow these provisions. ... these provisions, like the rest of the NCC, are minimum standards. Nothing stops you from going beyond the minimum standards set by the NCC. So, if you are dealing with an area which is prone to condensation, then there's nothing stopping you and it's probably a good idea to go beyond the minimum standards. There is ongoing work going on in condensation, it's still on our work program, and so, it's very likely you're going to find some new provisions again in NCC 2022 covering condensation." [46]

On the 27th August 2022 the building ministers agreed 7 star NatHERS ratings as the new benchmark for NCC 2022. Combined with improved vapour permeability requirements this brings us to a new era in building performance.

3.3.7 The building science era

Now a new era is emerging, as the use of vapour barriers falls into the spotlight, the main question arising in building physics is: how do we control water vapour within the structure?

A vapour barrier on the inside can prevent the risk of condensation in the winter. However, in summertime weather conditions there is a significant flow of water vapour inwards from high external temperature and high humidity which will create risk of condensation on internal vapour barriers. Therefore, vapour barriers should not be used, and intelligent control of water vapour is necessary which reduces diffusion resistance automatically to transform into a diffusion open membrane. With these features constructions provide a high potential freedom from structural and moisture damage to achieve a healthy outcome for housing.

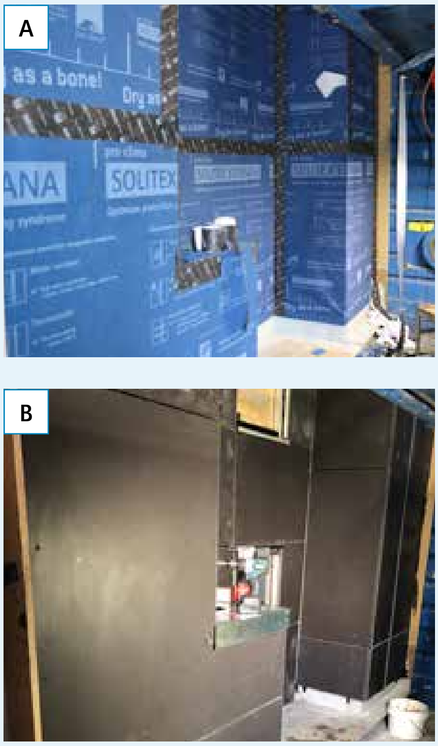


Figure 3.14: A full scale facade test of a drained and ventilated system with A) SOLITEX EXTASANA® WRB and B) Fibre cement cladding with a cavity, Ian Bennie and Associates, Melbourne, Australia.

Figure 3.15: SOLITEX EXTASANA ADHERO®, full adhesive backed membrane for high pressure system weatherproofing. Façade Testing NZ Limited, Wellington, New Zealand.

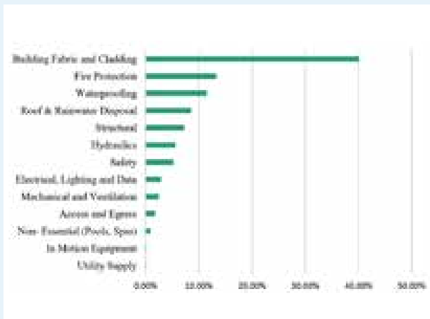


Figure 3.16: Percentage of Defects by Construction System across all Jurisdictions, Deakin University, 19 June 2019. Deakin report analyses growing number of apartment building defects.

Figure 3.17: In 2020, The Australian Institute of Refrigeration, Air-conditioning and Heating Released Design Application Manual DA07 Criteria for Moisture Control Design Analysis in Buildings.

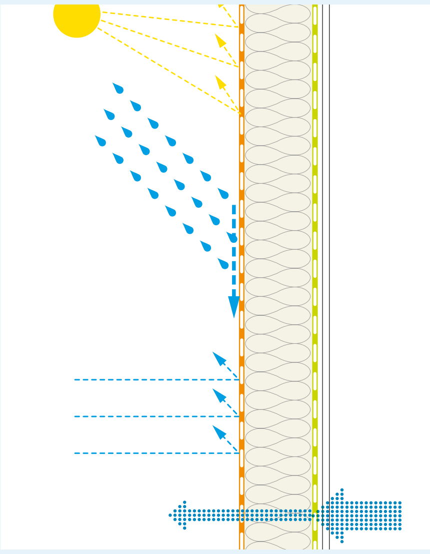


Figure 4.1: Requirements for external membranes. The cladding is the first line of defence deflecting the majority of water. The weather resitive barrier (WRB) is the second line of defence.

In 2020, the Australian Institute of Refridgeration, Air Conditioning and Heating (AIRAH) released a Design Application Manual 07 (DA07) Criteria For Moisture Control Design Analysis in Buildings (Figure 3.17) which helps guide us to answer these questions. [47]

3.4 The consequences: a lot of damages

3.4.1 NZ Leaky Buildings

In New Zealand, for example, the book "Rottenomics" by Peter Dyer was published, which shows the great extent of the damage and consequences individually and economically, surmonuting to an estimated $47 billion. [48]

Excessive moisture not only affects the building structure but also the health of occupants. The term "Leaky Building Syndrome" (LBS) is well established in NZ due to the extent of the pain caused by poor moisture management. A topic which is no longer debated and which will receive more and more attention and discussion in the future.

Important: LBS shows up at the outer layers of the building. BUT there are two reasons:

- water moisture from external leakages caused by rain, wind and weather (preferably windward side areas)
- water vapour from the inside caused by the lack of internal air barriers and vapour control layers. (all sides, also at downwind side areas)

Leakages caused by both reasons are concentrated at windows, doors and at special geographical parts of the building like corners, angles, nooks, etc.

3.4.2 Australian leaky building

On September 12, 2017, Kim Lovegrove RML, FAIB, Senior Lawyer, Lovegrove & Cotton, provided an overview of the Leaky Building Syndrome in Australia and internationally, including New Zealand.

"A leaky building syndrome is unfolding in Australia, although it has not yet reached the crescendo levels encountered in Canada and New Zealand." [49]

The ABC reported that with respect to Sydney, "a survey of strata owners conducted by the Research Centre in 2010 found that a startling 85 percent of respondents in buildings built since 2000 said their buildings were defective. The same article also reported that according to one estimate, 70% of the buildings leak." [50]

3.5 Summary

- The vast range of climate zones and rainfall patterns across Australia result in a difficult set of climatic variables and rain conditions for designers to contend with.
- The focus of building physics pertaining to membranes used in conjunction with insulation is most pertinent to framed structures built with masonry veneer or lightweight cladding.
- History has lead the insulation industry down the path of vapour barrier membranes used on the outside of predominantly fibrous insulation materials. This results in the perfect condensation trap. As we continue to increase the weathertightness of our buildings they are becomming more airtight on the outside building components. This then poses a risk of trapping moisture behind vapour impermeable waterproofing systems. The ABCB has acknowledged that condensation requirements has attempeted to address the issue but "there's nothing stopping you and it's probably a good idea to go beyond the minimum standards."
- Evidence is emerging that Australian residential properties are not suitably managing the exterior rain loads on the buildings as well as poor management of the interior water vapour resulting in interstitial accumulation of moisture within the building envelope.
- Intelligent Air Barrier on the inside of the insulation must be considered as a solution to prevent interstitial condensation.
- Widespread publication of the issues in academic journals, goverment inquiries and building code board invesitgations clearly supports this.
- NZ has experienced $ 47 billinon in damages from leaky buildings.
- Australia is on a similar trajectory, until now very few solutions have been clearly articualted to industry.
- The solutions presented in this study aim to avoid damages by presenting construction solutions which focus on correct planning, good workmanship and internationally validated building physics focussed innovation.

4. Function and properties of weather protection sheets

The primary purpose of a building is to protect the occupants from the weather. To achieve permanent and effective weather protection, the building structural elements must be protected from damage by rain and wind, excessive thermal stresses and condensation while at the same time insulating against energy losses. The task is therefore to plan and execute building work in such a way that mould cannot occur and such that the onset of biolgical decay within the structural materials is prevented. As a result the occupants will have a healthy living space and healthy air to breathe.

4.1 Effective weather protection

Effective weather protection is achieved by two separate and essential layers: the "first line of defence" and the "second line of defence", see Figure 4.1. The "first line of defence" is the façade (cladding) or the roof covering. It provides protection at the first direct level against water penetration into the construction from the outside by diverting (deflecting) rainwater away from the building component. It is easy to assume that this layer sufficiently protects the construction if the outermost protective surface of the construction (facade or roofing) are sealed and made as watertight as possible. But this is not the case, as we have learned from local and international experience: this layer is by no means reliable as a permanently watertight layer against weather influences, such as rain, wind and water vapour. Leaks in the outer layers are caused by aging processes, among other things. This aging is caused by the influences of sunlight (UV radiation), temperature cycling, wind pressure and precipitation. They can also be caused by different material behavior (expansion & contraction), favored by complicated component geometries and of course by manufaturing or installation defects (poor workmanship). The leaks can become easily visible to the naked eye, such as obvious cracks, or they can be invisible, such as micro-cracks and poorly sealed connections to other components.

4.1.1 Risk of leaks

It is not the flat material surfaces that are primarily at risk, but the connections to built-in components, such as windows and doors that become the weakest point of failure, see Figures 4.2 – 4.4.

When considering water ingress past the first line of defence in the design of weatherproofing systems, the question is not "IF water penetrates the cladding" but "WHEN water penetrates the cladding" which means we need to design assuming the cladding will leak.

Furthermore, problems with regard to the building's weathertightness can occur in exposed parts of the building, such as corners or recesses in the façade.

The most important layer for functional waterproofing is the "second line of defence". This layer of components behind the façade protects the structure against liquid water when it penetrates the first line of defence. In timber construction these are generally classified as Weather Resistive Barriers (WRB) which may be a pliable membrane (commonly known as sarking or underlay) or rigid sheathings (commonly known as rigid air barriers). These are glued and sealed together at junctions and overlaps using adhesive tapes or connected to adjacent building components to achieve a watertight construction. SOLID acrylate adhesives, such as the pro clima TESCON EXTORA® adhesive tape are superior to standard water-based acrylate adhesives because they offer outstanding water resistance and maintain adhesion in damp moist conditions, see Figure 4.5.

In all buildings (timber and masonry construction), great attention must be paid to window seals ensuring a continuous and permanent watertight connection between flexible or rigid WRBs and the window frame.

4.1.2 Lifetime & durability

It is crucial that the "second line of defence" is made of materials that have the longest possible service life. Past experience has shown that the number of deficiencies in weather protection membranes can be so high in specific countries that their effects, experiences and findings are discussed at specialist symposia, studies and books have been written, e.g. the book "Rottenomics" by Peter Dyer, published in New Zealand, which presents not only individual damage but also economic damage up to $47 billion. [52] A common term in the oceania region is now "Leaky Building Syndrome"

Figure 4.2: Image of failed caulking joint. Caulking cannot be relied upon for a permanently waterproof cladding system this was one of the main contributors to the canadian condo crisis. The first line of defence is subject to temperature flucuations (<0 to 100 °C) as well as UV. Degradation and eventual failure is certain. [51]

Figure 4.3: Left: Recently installed membrane. Right; Three months exposure, Sydney Australia.

Figure 4.4: Interfaces between the cladding material and built in components are often abutted and not sealed. This will leak when rain and wind are present. [53]

Figure 4.5: SOLID Acrylate adhesive used in pro clima TESCON EXTORA® is not water based in manufacture, i.e. there are no emulsifiers used with the risk of re-emulsifying. The manufacture is free of water and therefore the glue is resistant to water and high humidity.

Figure 4.6: Poorly installed membranes with no connection between the window and the WRB system provide a pathway for water ingress.

(LBS). The building practices leading to this have been denounced as "state of the art" and will receive more and more attention and discussion in the future., see chapter 3.3. How we got here!
Often the focus is on weighing up the cost of implementing quality sealing against quick & cheap application in the construction phase, but more important is the longer-term benefits in the occupation phase. This is also where the Leaky Building Syndrome becomes apparent, often only after several years of occupation.

In principle, the higher the quality of the Weather Resistive Barrier membranes and the seals, the more advantageous the building is to the occupants and to society as a whole. The simpler and clearer the installation technique, the resulting construction will be more fault-tolerant and the safer it will be against structural damage. Protecting against water damage applies equally to the relatively short construction phase as well as to the much longer occupation phase, which can last many decades.

The more windtight the Weather Resistive Barrier is, including all the connections to built in components then the lesser the risk of forcing water through, and the more weathertight the construction will be.

4.1.3 Reduced drying

The increased weather-tightness reduces the drying by virtue of air leakage increasing the risk of condensation behind this "second line of defence". The associated condensation behind the "second line of defence" is largely determined by the membranes in combination with the sheathing material properties and ability to allow water vapour to pass.

In this study, the solutions for flexible wall underlays are discussed.

4.2 Rain and water tightness

With regard to rain protection from the outside, the basic rule is that water must be kept away from the respective building component and the building facade itself, or the water must be drained away. Otherwise the materials contained in the building component may become damp and permanently impair or damage the construction.

This problem is much more severe for horizontal building component surfaces but is also a significant risk on inclined and vertical building component surfaces.

4.2.1 Protection in construction phase

During the construction phase, high intensity rainfall can directly hit the Weather Resistive Barrier membranes prior to cladding installation. The effectiveness of the membrane as a barrier against water is the primary property required here, considered in combination with other key performance parameters of building physics, such as vapour diffusion and wind- or airtightness.

The wind & airtightness is fundmental for temporary weather protection and the connections at WRB overlaps, joints, terminations to other materials must be sealed. Most critically overlooked are fixing penetrations (screws or nails) that are often the leakage point during construction phase.

4.3 Wind and air movement

In addition to the functions already described, the second line of defence also has the task of protecting the construction or the insulation level from air flow. These have an enormous influence on energy efficiency. If, depending on the season and region, cold or warm air flows through the construction, this results in a reduced efficiency of the thermal insulation measures, as well as increased cooling or heating of the construction and more energy must be used to create a comfortable indoor climate.

What are the effects of a building being exposed to the wind? On the side of the building facing the wind, an overpressure (positive) is created - on the side facing away from the wind, a underpressure (negative). If there is turbulence, e.g. at the corners of a building, zones of both positive and negative pressure can be created.

You can find out how strong the fluctuations in pressure can be with an umbrella in the wind.

If there is overpressure on one side or part of a building, outside air can be forced into the building through leaks in the outer shell. At the same time, internal air is sucked out of the building on the side of the building facing away from the wind, where negative pressure prevails.

Wind leaks in the second line of defence can occur over a large area through a porous structure by forcing air through the pores. Non-porous materials such as the TEEE membrane, on the other hand, are always airtight and thus also windproof and protect the underlying layers of the component very well against air movement from outside. Leakages in the second line of defence can also occur at the connections between the materials and their connections to other components due to planning or workmanship defects, see Figure 4.6.

Wind can carry moisture deep into the construction not only in the form of liquid water, i.e. via rain, but also via high humidity, resulting in unexpectedly high material moisture levels. There is a risk of structural damage and mould. In leaky buildings, windproofness plays a significant role in weather exposure and external humidity.

Wind and rain present at the same time is a force to be reckoned with. BRANZ research from the fallout of Leaky Building Syndrome found:

"Wind acting on a building creates a pressure difference between the higher pressure outside and the lower pressure inside. The design of a wall system must incorporate an undamaged barrier to resist these wind pressures and to avoid any air leakage paths to the interior of the building. If an air leakage path exists, water can be carried along it into the wall assembly. **If not provided with effective air seals, any gaps, joints and junctions in the wall cladding can become air leakage paths that can carry water when present.**" [54]

4.3.1 Effective weather resistive barrier

An effective Weather Resistive Barrier (WRB) system is one which is wind tight (air tight) as possible using water barrier materials. This enables the effective control of water ingress through small gaps and cracks induced by wind pressure.

The higher the air resistance and the greater the water barrier the better the product will operate as an effective WRB.

Some cheap water/vapour barrier products are perforated to make them vapour permeable. These perforations allow for water vapour to pass through the holes but also render the WRB ineffective for their primary purpose of waterproofing, see Figures 4.7 – 4.10.

As perfection is generally impossible at best a waterproofing system can only be described as "resistive" with the aspiration of achieving a perfect "barrier" to wind and water. In this context some water is always possible to enter the construction even with the best designed and implemented system, which is where vapour permeability is necessary to improve resilience in case of imperfections.

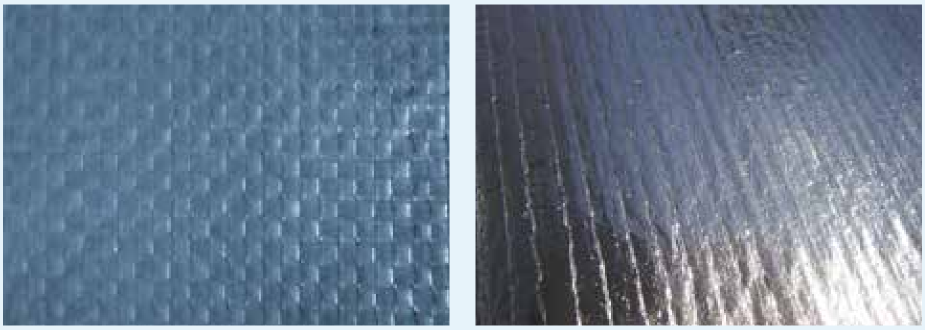


Figure 4.7: Vapour barriers usually contain a layer of aluminium foil. The foil itself is vapour impermeable and has no ability to allow structures to dry.

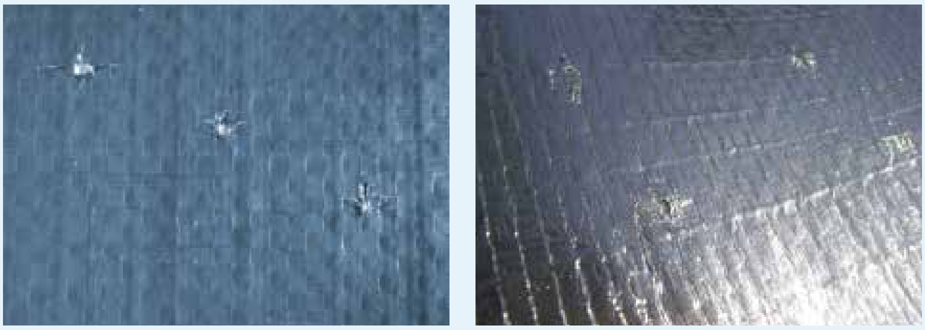


Figure 4.8: Perforations are often used to make a vapour barrier into a vapour permeable membrane. These can not be considered weatherproof as they do not meet the water barrier or air barrier properties necessary to provide weatherproofing necessary on the second line of defence and wind tightness required to enable the cladding to function effectively.

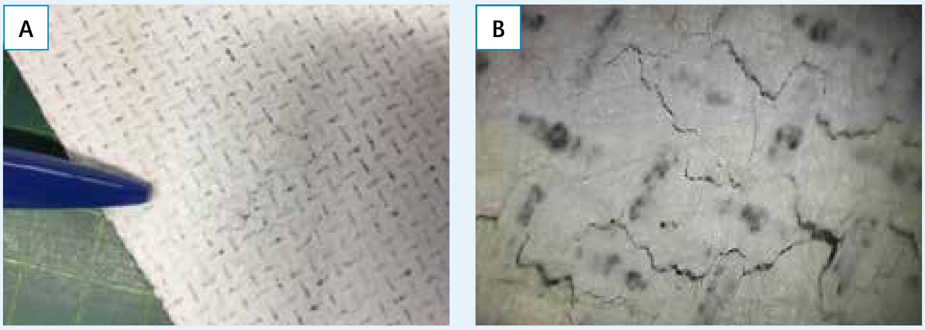


Figure 4.9: Early vapour permeable membrane technology utilising microporous membranes suffer from durability problems. A) 5 years of real aging and damages in the roofing membrane are already visible to the naked eye, B) the microscope reveals the cracks that lead to a lack of water tightness.

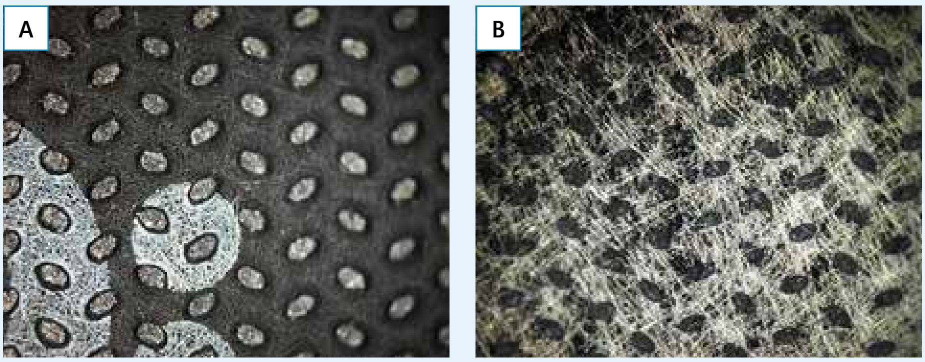


Figure 4.10: New generation technology utlising monolithic interlayers provide durable and reliable water barrier and air barrier porperties for long term damage protection. 5 years of real aging, A) front side, B) back side.

Figure 4.11: Membrane buldging under 10,000 mm of water column. Equivalent to 10 kPa or 1000 kg/m² of weight the membrane buldges but does not leak.

Figure 4.12: Thermoplastic Elastomer Ether Ester (TEEE) film is sandwiched between 2 protective fleeces.

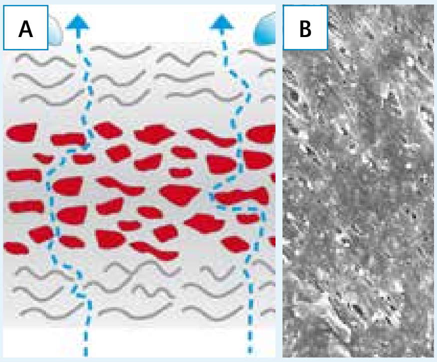


Figure 4.13: Traditional microporous vapour permeable membrane – low saftey margin. A: Passive diffusion transport. B: Microscopic detail of a porous membrane.

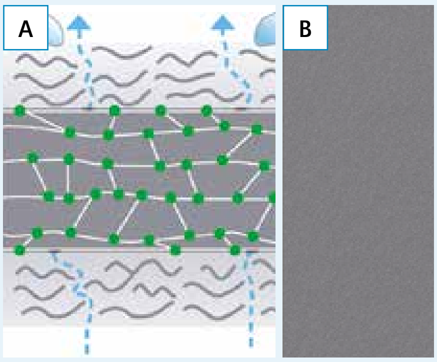


Figure 4.14: SOLITEX non-porous memrbane – optimum protection. A: Active diffusion transport. B: Microscopic detail of a porous membrane

4.3.2 Water "barrier"

The water barrier properties of Weather Resistive Barrier membranes is tested in various ways. Internationally, the hydrostatic head according to EN ISO 811 is the most common. The load acting on the weather protection membrane from a water column simulates the pressure exerted by water and wind. The higher the water column of the weather protection membrane is, the more effective the material is as a "barrier" and the better the construction is protected against water penetration. High quality membranes have a water column of over 10,000 mm, reinforced membranes of 2,500 mm, see Figure 4.11.

In Australia, the "resistance to water penetration" test of Weather Resistive Barrier membranes (pliable building membranes) is common in accordance with the AS/NZS 4201.4 standard. In this test, twelve test samples are exposed to coloured water at a height of 100 mm for 24 hours (approximately 1.0 kPa static pressure). The test is considered passed if no liquid is visible on the backside of the sample within 24 hours. Water pressure caused by wind and rain is not taken into account here.

The combination of both properties is ideal. On the one hand, high-quality weather protection membranes should be able to withstand the energy input, the simulated pressure from water and wind (water column >2.500 mm), as well as the longer-term load (0.10 m dam height over 24 hours).

4.4 Membrane structure

3-ply WRB membranes are advantageous: fleece – membrane – fleece. (Figure 4.12) The upper fleece plays a major role in the strength of the membranes. It protects the functional film from mechanical damage and UV radiation. The lower fleece protects the functional film from damage to the back of the weather protection membrane, e.g. during laying.

The functional film is the layer that ensures water and moisture tightness. Currently, two types of functional films are used for vapour permeable underlays and façade membranes: Monolithic and microporous membranes.

4.4.1 Monolithic & microporous membranes

Monolithic films are non-porous and therefore absolutely waterproof, see Figure 4.11. Films with pores have a reduced waterproofness because water can penetrate the membranes more easily through the pores. With porous films, attempts are made to achieve waterproofness through particularly small pores, see Figure 4.13. These functional films make use of the surface tension of the water, which hinders the transport of water through the small pores. However, if the surface tension is reduced, e.g. by the salts or detergents/surfactants often used in Australia in the wood preservatives of the timber used, the waterproofness of the microporous film can be reduced significantly, see Figure 4.15 – 4.17.

4.4.2 Monolithic TEEE

When developing the TEEE film, the aim was to find and further develop a functional film that is absolutely waterproof (even under chemical influences), vapour diffusible, temperature stable and durable.

More than two decades ago the polymer of the airbags - the TEEE - Thermoplastic Elastomer Ether Ester - was selected for that use. The functional films of the airbags are monolithic, naturally free of pores, temperature stable and durable. This plastic has a melting point of about 200°C, which is twice that of polyethylene, and is thus characterised by extremely high thermal stability. This characteristic is very positive for hot summer temperature for example at the beach in Brisbane or for very cold winter temperature on the ski field in Thredbo. Now the vapour diffusion was still missing. This could be achieved by polymer adaptation with regard to the ester and ether configuration.

The TEEE membrane used in the pro clima SOLITEX EXTASANA® and SOLITEX MENTO® family reaches hydrostatic pressures of more than 10 m water column (2.50 m for the reinforced membranes). This means that the membranes are still waterproof at a pressure of more than 100 kPa (25 kPa for the reinforced membranes) - this is an example of the technical superiority of pro clima "sarking" membranes.

The monolithic TEEE membrane with its non-porous structure is resistant to chemical stresses common in construction, such as the salts of wood preservatives and the wetting agents (detergents) that are added to help the salts penetrate the wood. It is also resistant to oil, e.g. from chain saws. (Figure 4.18 – 4.20)

Salty sea air also has no influence on the waterproofness of the TEEE membrane. This is essential for the weather protection of buildings built in the vast coastal regions

across Australia.
The TEEE membrane integrated between two layers of protective fleece is unique in its ability to fulfill the requirements for: High diffusion permeabilty, active diffusion transport, rain impermeability, windtightness. (Figure 4.14)

4.5 Vapour diffusion and condensation

Vapour diffusion causes moisture in solid materials to be transported from the side with the higher partial water vapour pressure to the side with the lower partial water vapour pressure - i.e. as a rule from higher temperature to lower temperature. If it is warmer inside than outside, vapour diffusion is directed outwards (winter climate). If, on the other hand, it is warmer outside the building than inside (summer climate), the diffusion of moisture is directed towards the interior, see chapter 2.

4.5.1 Direction of vapour flow

It is known that diffusion is not a “one-way street = one direction”. In the case of a diffusion flow directed from outside (when outside is warmer) to inside (when inside is cooler), the moisture load from outside acts on the construction. In this case a very diffusion-open construction can be unfavourable, in that too much water vapour from the outside penetrates into the building component and then condenses on the inside on the air seal, the interior cladding (plasterboard with paint) or other scenarios related to occupant behaviour (behind cupboards, pictures, etc. on the outside wall).
Only in the period with lower outside temperature compared to the inside temperature does a high vapour permeability on the outside offer advantages: When moisture on the outside dries out of the component faster than it comes in from the inside. Due to the limits of WRB material technologies extremely high diffusion permeability is often accompanied by a reduction in the water barrier function, especially when wood preservatives, salts and oils are involved as shown in Figure 4.15 – 4.17.

4.5.2 Moisture damage by diffusion

In many cases, moisture damage is often first identified behind the WRB. The first assumption is that the moisture comes from the outside - but it can also often come from the inside and is caused by warm, moist air

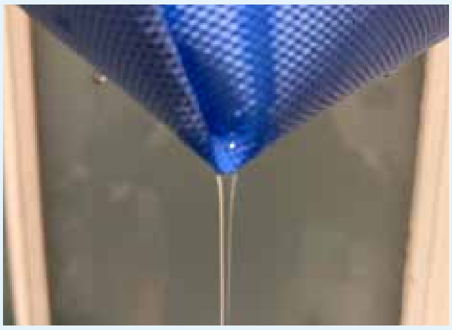


Figure 4.15: Low cost membranes can be affected by surfactants such as wood preservatives, oils and grease lowering the surface tension and therefore their ability to maintain water barrier properties. This image shows water leaking through the membrane due to the effects of a surfactant. This particular membrane has no functional layer.

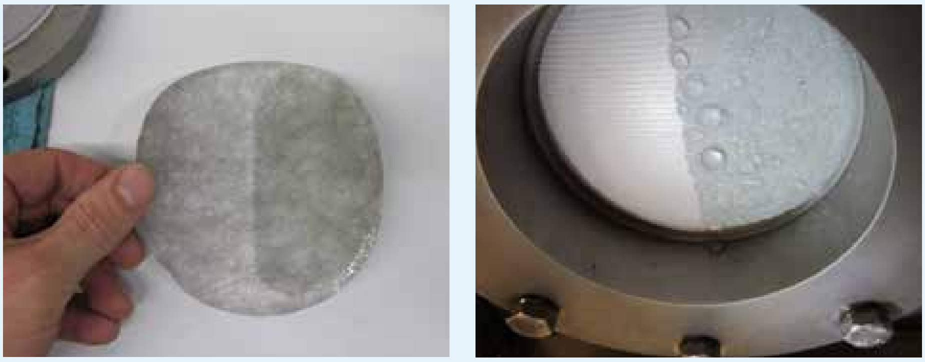


Figure 4.16: Microporous membrane when subject to surfactant such as oil, grease of timber tannins will allow water molecules to leak through the micropores. Left: oil applied to helf the sample. Right: Leakage occurs through the microporous membrane half applied with oil.

Figure 4.17: Non-microporous TEEE membrane when subject to surfactant such as oil, grease of timber tannins will remain water tight. Left: oil applied to half of the sample. Right: TEEE membrane remains unaffected.

Figure 4.21: Vapour barriers can trap moisture on the cold external side of a construction system. Although this may appear to be a water leak it is actually the long term accumulation of water vapour attracted to the coldest surface. Clearly identifiable is the damage to the timber on the outer side of the studwork but not on the inside (warm side). [55]

Figure 4.22: Mould growth caused by back diffusion in Mackay, Australia. [56]

Figure 4.23: Fine layer of mould growth on ceiling caused by back diffusion in Cairns, Australia. [57]

from the living area diffusing into the outer layers of the building component and condensing on the cold WRB. Without an airtight layer such as pro clima INTELLO® PLUS on the inside, the Leaky Building Syndrome will hardly disappear. As already mentioned, this can cause:

- moisture in the outer layer of building components from the outside due to wind and rain and/or
- moisture in the outer layer of building components coming from inside due to air leaks

Both accumulations of moisture are mostly visible on windows and doors.

4.5.3 Back diffusion

The higher the humidity and temperature on the outside, the higher the external diffusion resistance should be. In all climate zones it is possible to use façade membranes with a diffusion resistance of 0.4 – 0.88 MNs/g (class 4: vapour permeable e.g. SOLITEX EXTASANA®) for ventilated façades.
Although the required membrane may be more resistant in climate zone 1. It should still considered vapour permeable by class 3 of AS/NZS 4200.1 (<7 MNs/g). A perfect execution is a rigid WRB plus SOLITEX EXTASANA ADHERO®, which is glued on the boards. This membrane should be as vapour permeable as possible and only as vapour resistive as necessary. In the tropics slightly higher vapour resistance is necessary. See calculations and information in chapter 6. In the past, aluminium foils caused extremely high levels of structural damage in colder climates and are now banned in climate zones 6 – 8 according to Australian standards. However, they are also often viewed critically in other climate zones, see chapter 3 and chapter 6.
The focus of building physics pertaining to drying capacity deliverd by membranes when used in conjunction with insulation is most pertinent to framed structures built with masonry veneer or lightweight cladding.

4.6 Aluminium foils

In the past, aluminium foils caused extremely high levels of structural damage in colder climates and are now banned in climate zones 6 – 8 according to the National Construction Code (NCC). However, they are also often viewed critically in other climate zones, see chapter 3, 6 and 7.
The focus of building physics pertaining to drying capacity deliverd by membranes when used in conjunction with insulation is most pertinent to framed structures built with masonry veneer or lightweight cladding.

4.7 Timber frame protection

The robustness of brick veneer is well proven, partly due to the well-entrenched building practice utilising a 50 mm cavity (at least 35 mm clear) separating the moisture sensitive timbers from the masonry with a drained and ventilated cavity.
Lightweight clad structures on the other hand, with either timber, fibre cement or metal cladding may not require a cavity according to the National Construction Code (NCC).
Where the cavity can be used to decouple the cladding properties from the insulated, weathertight, and airtight part of the construction. The cavity may be open at the bottom only for drainage and at best this can be considered vented. If the cavity is open at the bottom and at the top it promotes drainage and ventilation by stack pressure. The use of cavities behind the cladding means the properties of the cladding itself become less relevant than direct fix systems when the only way to get moisture to dry from the system is by water vapour permeating through the cladding itself. When metal cladding is used, it becomes impossible to dry through the cladding and a ventilated cavity should always be present to move water vapour around the metal barrier safely to outside.

4.8 External cladding properties

Fibre cement and timber can vary in the vapour diffusion characteristics, but more importantly paint finishes, protective vanishes, texture coats or render coats will all affect the ability of the system to dry. Until the scientifically tested hygrothermal performance of these coating layers commonly available in Australia is improved, it is prudent and wise to maintain a cavity in all systems. The need for the cavity can be roughly guided by the expected amount of rain in any given location. As a guide Table 4.1 illustrates the possibilities. As building practices improve we need to consider how these traditional methods can be made more weathertight. It is important we consider the mechanical characteristics and forces of the wind pressure on the WRB to ensure long term weathertight houses resulting in permanently healthy and more durable dwellings. The weatherproofing systems should be able to handle wind pressure on the outside and resist damage enabling it to maintain condensation management function based on the appropriate vapour diffusion characteristics of the membrane for the climate.

4.9 High wind (cyclonic)

In high wind scenarios and tall buildings with high wind exposure, it should be used a rigid support board behind the membrane to prevent billowing movement of the membrane. Best solution would be to glue SOLITEX EXTASANA ADHERO® as pliable WRB on top for both perfect protection in the construction phase and for damages of the facade e.g. caused by severe stormes.

4.10 Typical construction assemblies

In Australia construction assemblies are built with and without cavities behind the cladding. This has a large impact to the risk of water ingress and of the capacity to remove moisture from the system.

- **Face sealed:** No opening to allow for water drainage or ventilation behind the cladding.
- **Drained:** Bottom openings to allow water to drain out, using a capillary break separation layer.
- **Vented:** Airflow in/out of the same dedicated bottom opening, where cladding is battened off from the WRB.
- **Ventilated:** Airflow in and airflow out simultaneosly at the bottom and top of the wall where cladding is battened off from the WRB.

Figure 4.24 shows the dominance of brick veneer across the eastern states, the outliers are Western Australia dominated by cavity brick, and northern territory dominated by heavy mass concrete construction. The tropical climates of Far North Queensland (FNQ) is dominated by heavy mass construction similar to the NT but is not apparent in the state based statistics due to the dominance of brick veneer in South East Queensaland. The key performance driver being the durability against cyclonic winds.

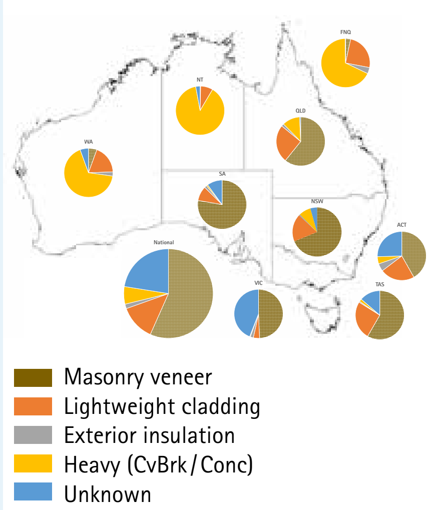
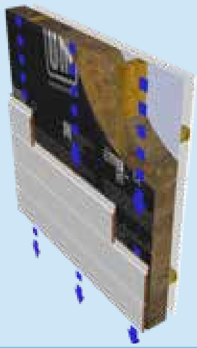


Figure 4.24: The dominant construction types in Australian regions [58]

Minimum cavity and drainage recommendations	Face sealed direct fix	Drained
Lightweight / weatherboard (Low rise & non cyclonic N1 – N4)		
Brick veneer (Low rise & non cyclonic N1 – N4)		
Lightweight / weatherboard (High rise & cyclonic N5 – N6)		
Brick veneer (Low rise cyclonic N5 – N6)		
Heavy masonry & concrete blockwork (Low rise cyclonic N5 – N6)		
Normal rain	≤ 500 mm/yr	500 ≤ 1000 mm/yr

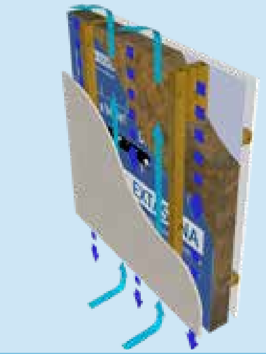
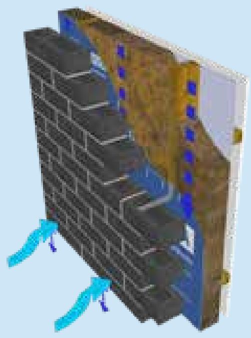
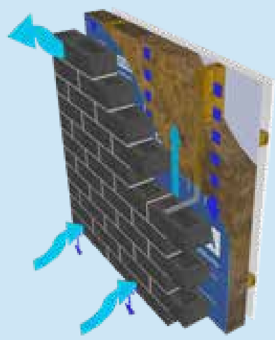
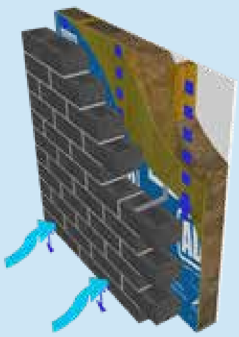
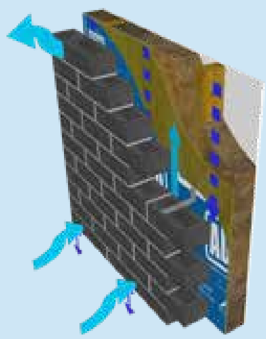
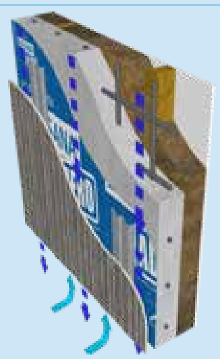
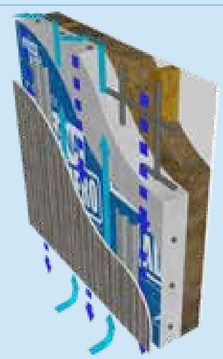
Drained and vented	Drained and ventilated
	
	
	
	
	
1000 ≤ 1500 mm/yr	> 1500 mm/yr

Table 4.1: Possible design strategies in accordance with the Australian Building Code and best practice

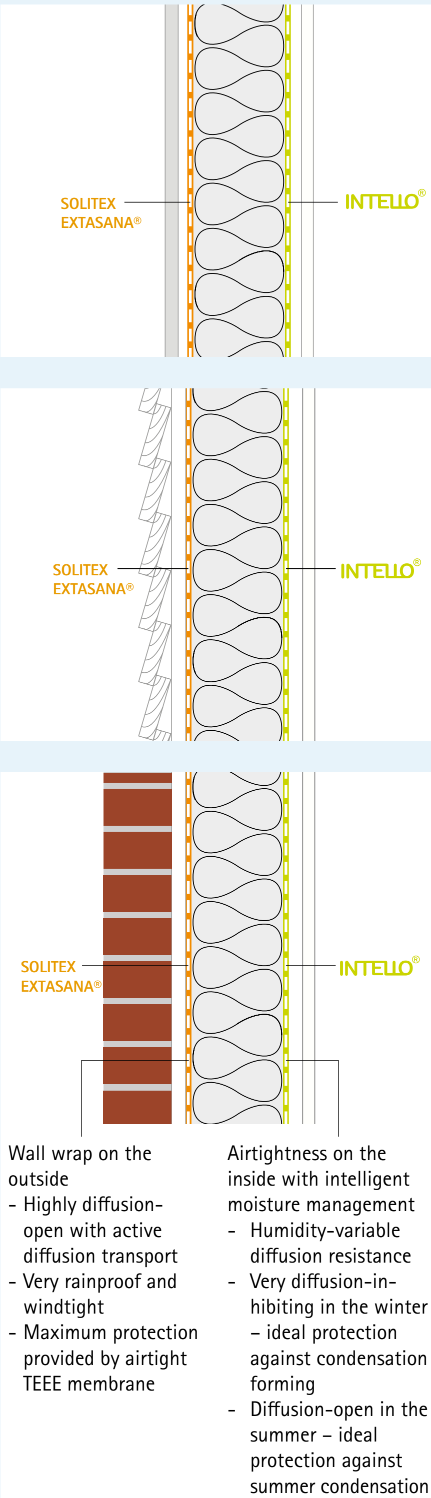


Figure 4.25: A well protected lightweight wall or brick veneer construction in climate zone 2 – 8

4.11 Summary

- Buildings need a second line of defence in the form of Weather Resistive Barriers, since facades as a first line of defence do not provide absolutely tight weather protection (ageing, processing defects, planning errors, material coordination, etc.). WRB can be rigid sheathings or pliable wall membranes or a combination of both.
- Leaky Building Syndrome (LBS) is a term used to describe structural damage to the external wall. This term can no longer be negated as "state of the art". It is intensively discussed in specialist circles and specialist books on the subject are also published, such as the book "Rottenomics" by Peter Dyer, which was published in New Zealand. In addition to individual losses, it also describes the economic loss (NZ$ 47 billion loss).
- The higher the quality of the weather protection membranes, the more advantageous the building physical properties and the simpler and clearer the laying technique, the more fault-tolerant the construction is and the more secure it is against structural damage. This applies equally to the construction phase with short and intensive water exposure as well as to the occupation phase with continuous and weak water exposure, which lasts for decades.
- The TEEE membrane of pro clima weather protection membranes is based on the polymer technology of airbags. The moisture-active vapour diffusion performance was achieved by polymer adaptation of the ester and ether configuration.
- The TEEE membranes have a high level of rain and water resistance (water column without reinforcement 10,000 mm, with reinforcement 2,500 mm high) and offer the construction the best possible protection against external rain loads.
- The non-porous membranes are naturally highly air- and windproof. This means that the underlying thermal insulation retains its functional performance.
- The pro clima TEEE membranes are characterised by their insensitivity to wood preservative loads and oils from chainsaws and guarantee high impermeability to rain and water even under these conditions. The polymer configuration offers a high stability against sea salt loads from the air.
- A diffusion resistance of between 0.4 – 0.88 MNs/g (class 4: vapour permeable) offers advantageous moisture dynamics: both a high evaporation potential from the inside to the outside (good drying out in winter climate) and limited humidification from the outside to the inside (low back diffusion, i.e. accumulation of moisture in summer climate).
- Microporous membranes have a water vapour exchange passively via air exchange (= vapour convection), TEEE membranes on the other hand actively via the molecular chains (vapour diffusion). Active water vapour transport reduces the risk of condensate precipitation on the lower surface of the membranes.
- The SOLID acrylic adhesive is water resistant (no re-emulsification of the adhesive), is therefore safer to use and has a higher durability when exposed to liquid water and/or high humidity. This reduces the risk of LBS in the event of weathering, damage due to processing defects, etc.
- Aluminim foils on the outside are not suitable in the climate zones 6 to 8 (NCC 2019) because of the high condensation and the accompanying mould, mildew and decay, but aluminium foils on the outside must also be viewed critically in the warmer climate zones
- The Leaky Building Syndrome can have two causes: Moisture accumulating in the outer layer of building components from outside due to wind and rain. Moisture accumulating in the outer layer of building components coming from inside due to air leaks. Both accumulations of moisture (condensate, liquid water, rain or high humidity) and damage are mostly visible in the wall close to the adjacent components like at windows and doors.
- Until the scientifically tested hygrothermal performance of paint finishes, protective vanishes, texture coats and render coats layers commonly available in Australia is improved, it is prudent and wise to maintain a cavity in all systems.
- In high wind scenarios rigid support board behind the membranes prevents pressure generated movement of the membrane.
- Construction systems design can incorporate openings at the bottom and top of the wall which can be broadly classified into: face sealed, drained, drained/vented and drained/ventilated.
- Good weatherproof WRB systems should be combined with interior vapour control strategies that allow winter and summer moisture protection (Figure 4.25) to prevent mould growth. This will be discussed
- further in chapter 5 & 6.

5. Calculating of moisture content and mould index in building structures

5.1 Calculation methods

There are steady-state and transient methods for calculating the moisture load in building envelopes. Steady-state methods are highly simplified calculation methods that, firstly, only reflect the environmental conditions very imprecisely and, secondly, greatly simplify the building materials too.
Steady-state methods are useful for obtaining a rough assessment of constructions but are not suitable for evaluating the real-life environmental effects and moisture transport processes within building envelopes.
Transient methods are capable of analysing moisture transport processes within building envelopes realistically.
Material properties such as capillary suction and vapour sorption behaviour are only taken into account by such methods, which calculate the heat and moisture transport on the basis of real environmental climate conditions.

5.1.1 Steady-state calculation method in accordance with ISO 13788

The ISO 13788 standard specifies the method used for calculating the amount of condensation in constructions. The year is simplified by being broken down into 12 blocks, each block for one month. The meteorological data for each of the blocks is constant, which is why this method is described as steady-state, as it doesn't take any real environmental conditions into consideration no day and night difference. The results are merely a rough approximation and can on no account be taken as a realistic representation of the actual moisture transport processes within a construction. [59]

5.1.2 Transient calculation method

Dynamic computer programs can be used to simulate moisture movements realistically for a specific construction and based on the actual location climatic conditions.
Well-known computer programmes are Delphin, developed by the Institute for Building Climatology in Dresden (Germany) and WUFI® Pro [60] developed by the Fraunhofer Institute for Building Physics in Holzkirchen (Germany). See Figure 5.1.
Both of these programmes take the coupled heat and moisture transport of multi-layer building constructions under actual climatic conditions into consideration. Transient methods take meteorological data into consideration to calculate the processes occurring within the building construction and its materials.
This means the calculation relates to the actual temperature and humidity, sunlight absorption, wind and cooling due to evaporation, day and night conditions, etc. In addition to this, the properties of the building materials are considered in detail and factors such as absorption and capillary action are also included in the calculation.
The simulation calculations have been validated many times: the results of the calculation are compared to actual building investigations and confirmed.
To calculate a simulation, the building component is entered into the programme together with its layering sequence. Then, the heat and moisture movements within the material is simulated each hour, i.e. in 8,760 individual steps per year (24 hours x 365 days = 8,760), over several years. The results of the simulation show whether moisture accumulates or reduces:
Whether the total moisture content of the structure over the period under consideration rises or whether it stays dry. AIRAH DA07 suggests simulation periods a minimum of 10 years as it can take years for moisture to accumulate before it causes damage. In Australia damages are often observed after the 3-5 year mark.
It is also possible to determine the moisture content of each individual layer of material. The moisture level at the boundary layers of a material indicates whether there may be a risk of mould and the moisture level within each layer indicated the level of risk for the building envelope as a whole.
The calculations in this study were performed using the simulation software WUFI® Pro developed by the Fraunhofer Institute for Building Physics in Holzkirchen, Germany.
The collaboration partners of IBP in Australia for ongoing research are CSIRO and the University of Tasmania. The partner for distribution, application and professional development of WUFI® professionals in Australia is Pro Clima Australia.
WUFI® Pro simulations give a realistic impression of the building physics for a wide variety of different constructions for all climatic regions. It is a catalyst for inno-

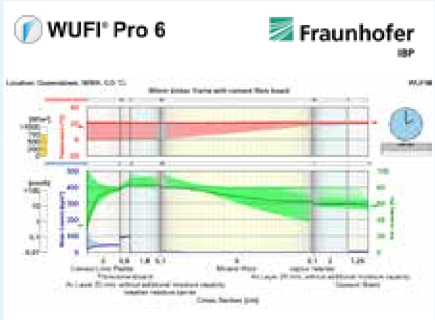


Figure 5.1: Computer assisted simulation programme for heat an humidity transport (dynamic). WUFI® Pro (Fraunhofer Institute for Building Physics, Germany)

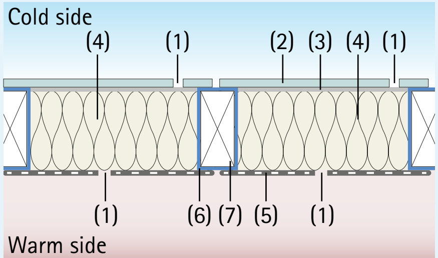


Figure 5.2a: Timber frame lab test construction from Fraunhofer IBP. One 5 mm hole was made in the centre of the warm side and extraction was made at the bottom of the cold side with 5 Pa pressure difference. Cross section of the lab test assembly. (1) 5 mm hole; (2) Perspex Sheating; (3) Paper sheets; (4) Fibrous insulation; (5) Aluminium sheeting; (6) Vapour barrier; (7) Timber rafter [61]

Figure 5.2b: The cold side [61]

Figure 5.2c: The warm side before the mounting between the hot and cold box. [61]

Figure 5.2d: Cold side with condensation forming evenly during test. [61]

Sensitivity class	Materials
Very sensitive	Pine sapwood
Sensitive	Glued wooden boards PUR with paper surface Spruce
Medium resistant	Concrete Aerated concrete Cellular concrete Glass wool Polyester wool
Resistant	PUR polished surface

Table 5.3: The sensitivity class of substrates is based on how easily mould can grow [62]

vation without taking unnecessary risks of failure.
The highest moisture load is normally expected in the colder climate zones 2 – 8 on the outside, and in climate zone 1 on the inside. For this purpose, the moisture and temperature profile of the boundary surfaces in these layers should be well investigated.

5.2 Risk assessment of mould growth on material surfaces

For some years now, mould growth models have been available to assess the risk of mould growth on material surfaces. These post-processors "WUFI® Bio" and "WUFI® Mould Index VTT", which are integrated in WUFI® Pro, allow for a representation of the mould risk depending on the respective relative humidity, temperature, time and substrate properties. Other calculation parameters such as the air exchange rate, the moisture load in the living space and the ventilation rate in façade cavities are included in the calculation.
WUFI® Pro can simulate concentrated moisture from localised leaks, even when there is a small hole as in the case with air leaks, the condensate occurs evenly onto external cold surfaces.
Tests were carried out at Fraunhofer IBP to see how a leakage on the inside of the construction looks, through which the air flows into the construction concentrated from a hole. This research aimed to answer what happens when warm air and thus the moisture in the air enters the construction cavity. Does condensate evenly distribute on the cold outside layers, or is there a concentration of condensate around the leakage point on the inside lining?
If the cavity is filled with thermal insulation, there is no unhindered air movement in the cavity. Then the amount of condensate does not concentrate at the outlet opening, but rather creates an even distribution of condensate over the surface. These findings lead to the conclusion that a one-dimensional WUFI® Pro model is suitable to assess point air leakages and more sophisticated WUFI® 2D models are not required in this case. This even distribution of condensate can be simulated in WUFI® Pro with the Air Infiltration Model IBP with the different Envelope Infiltration Airtightness Class A-C (1–5 $m^3/(m^2 \cdot h)$). A tighter envelope restricts the movement of moisture laden air and therefore the structure increases its moisture resilience.

The experimental set-up at the IPB and the system description. [61] is shown in Figure 5.2a – 5.2d.

5.2.1 WUFI® Bio

For the risk assessment of mould growth using the biohygrothermal method "WUFI® Bio", the moisture balance of the mould spores is modelled and compared with the critical water content at which spore germination occurs. If germination takes place, the subsequent strength of the infestation can also be estimated by comparison with growth curves.
The bio-hygrothermal method represents an assessment of the risk of mould growth, but not a simulation of the actual growth processes that is realistic in all respects. In particular, some model assumptions are "on the safe side", so that mould growth is more likely to be predicted than will be the case in reality. Furthermore, the model is only suitable for interior surfaces. On exterior surfaces, the influencing factors considered in the model (increased humidity) would indicate an excessively high risk of mould growth. In reality, building orientation other weather influences not taken into account often prevent mould growth (strong heating from sunlight, killing of the fungi by UV radiation, washing off by rain, etc.).

5.2.2 WUFI® Mould Index VTT

A mathematical-empirical model for the prognosis of mould growth on component surfaces and on material surfaces within the construction has been developed in cooperation between the Finnish Research Institute VTT and the Fraunhofer Institute for Building Physics. Hannu Viitanen and Tuomo Ojanen, among others, have been studying the growth conditions of mould on wood and other building materials for many years and have developed an evaluation method for this purpose - the so-called VTT model. [63] [64] [65] [66]
This evaluation option was integrated into WUFI® Pro VTT post processor. With the VTT model, a validated statement about the risk of mould growth can be made depending on the mould sensitivity of the respective building material, the ambient temperature and the relative humidity on site. The result is the so-called Mould Index (MI). See table 5.3.
Mineral fibre and glass fibre insulation is usually classified in the sensitivity class "medium resistant", but this classification

does not take into account all mould-promoting influences.
When humidity and temperature meet a surface (substrate), the combination of both creates a tendency to grow mould. High humidity and low temperature produces a low tendency to grow mould (for example, in a refrigerator food grows mould more slowly than at room temperature). Low humidity and high temperature is the same (dried fruit moulds more slowly than fresh fruit). However, we also know that not all foods in the refrigerator grow mould at the same rate. Some are more sensitive and others less. Some items (almost) never grow mould, like water bottles. However, if the refrigerator is turned off and the door is left closed for a long period of time (and it is warm in the refrigerator), then glass and plastic surfaces also become covered with a layer of mould, even though neither plastic nor glass can mould. The reason the mould is able to grow is because of the presence of organic substances on the surfaces, which provide a breeding ground for the mould.
Organic substances on surfaces are common on construction sites, e.g. as a result of wood processing (sawing, planing, sanding) on the construction site and dust blowing into/onto the construction site from outside, including plant matter such as pollen, etc. See Figure 5.4.
For this reason it is prudent to account for dust. The calculations presented in chapter 6, have not used the laboratory value "Medium Resistant" for glass wool as the Mould Growth sensitivity class, but instead "Sensitive".
Other substrates for mould are the wood components such as the wood structure, plywood panels, on the exterior, etc. In Australia, the wooden components may be impregnated against insects and mould, but even here there are plenty of organic components on the surfaces and mould resistance decreases over the years with permanent exposure to moisture. See Figure 5.5.
Therefore, this study assumes, even if in chapter 6 the MI index on wood-construction-parts is not calculated directly, the potential impact on other adjacent "sensitive" construction parts justify a "sensitive" value.

5.2.3 Evaluation of mould growth using the Mould Index

The Mould Index indicates the intensity of vegetation growth on a six-level scale. It takes into account that in longer dry phases a decline in mould coverage is possible.

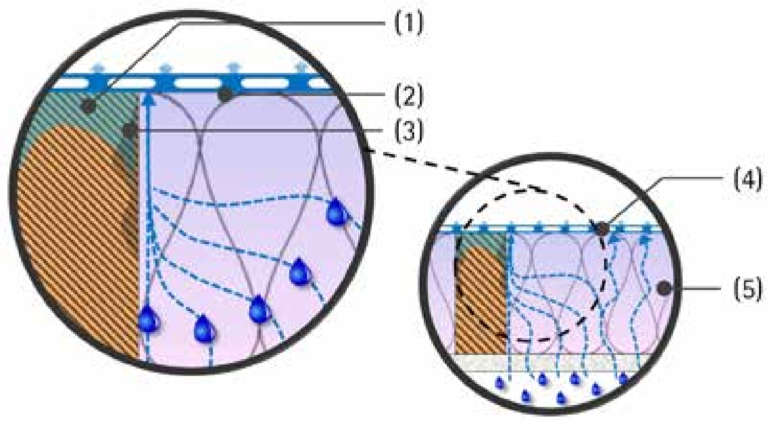


Figure 5.4: Mould sensitivity of mould resistant materials can be increased by construction dust. (1) High moisture content on cold side of stud; (2) Mould "sensitive" dust on membrane; (3) Mould "sensitive" timber studs; (4) SOLITEX EXTASANA®; (5) Batt insulation

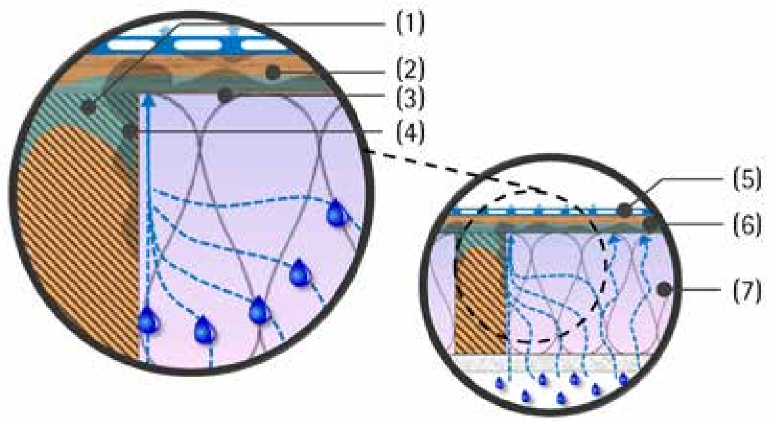


Figure 5.5: The surface of mineral fiber can be mouldy due to organic particles on the surface as well as timber board products and SOLID timber products which provide a cellulosic food source for mould. These materials are considered mould sensitive in the calculation of the study. (1) High moisture content on cold side of stud; (2) Mould moisture content in board; (3) Mould "sensitive" dust of membrane; (4) Mould "sensitive" timber studs; (5) SOLITEX EXTASANA®; (6) OSB / Plywood; (7) Batt insulation

Index	Description of the growth rate
0	No growth
1	Small amounts of mould on surface (microscope), initial stages of local growth
2	Several local mould growth colonies on surface (microscope)
3	Visual findings of mould on surface, < 10 % coverage, or < 50 % coverage of mould (microscope)
4	Visual findings of mould on surface, 10 – 50 % coverage, or > 50 % coverage of mould (microscope)
5	Plenty of growth on surface, > 50 % coverage (visual)
6	Heavy and tight growth, coverage about 100 %

Table 5.6: Descriptions of Mould Index as described in AIRAH DA07. Originally derived from experimental results by Finnish research institute VTT and the Fraunhofer Institute for Building Physics. [62]

Figure 5.7: MI = 0, No growth

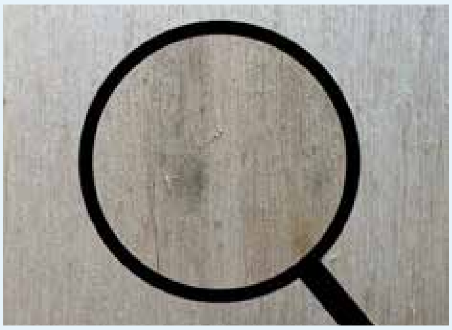


Figure 5.8: MI = 2, Serveral local mould growth colonies on surface (microscope)

Figure 5.9: MI = 3, Visual findings of mould on surface, < 10 % coverage, or < 50 % coverage of mould (microscope)

Figure 5.10: MI = 6, Heavy and tight growth, coverage about 100 %

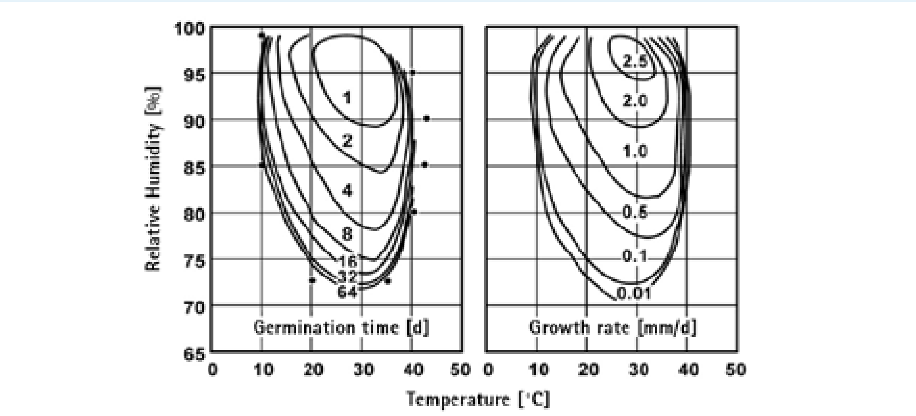


Figure 5.11: Shows the time it takes for mould to form as a function of temperature and humidity. At 30 °C, at 95 % relative humidity, it takes 1 day for mould to form. At 20 °C, at 75 % relative humidity, it takes 64 days for mould to grow. At 30 °C, at 90 % relative humidity, the growth rate is 2 mm per day. At 20 °C, the growth rate at 75 % relative humidity is 0.1 mm per day. [67]

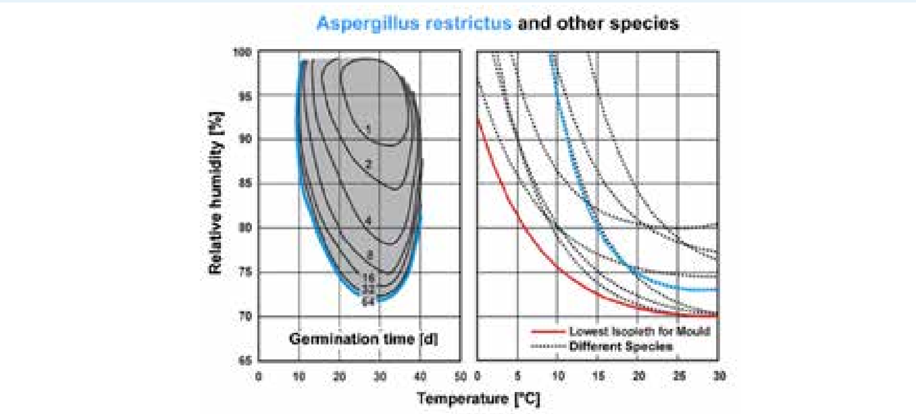


Figure 5.12: Temperature-humidity diagram isopleth systems for germination time and growth rate using the example of Aspergillus restructus (Smith). The lines of equal germination time are called isopleths. [67]

The Mould Index, which is determined according to the VTT model, allows a statement to be made about the intensity of mould proliferation on building material surfaces using a traffic light system.

With a Mould Index of 0 to 1, there is no mould growth or mould can only be detected very sporadically under a microscope (Figure 5.7). This area does not represent a relevant risk for mould growth and is classified as non-critical - the traffic light is therefore "green".

For material surfaces that show Mould Index 2 (Figure 5.8), mould growth can be seen with the microscope on larger surfaces. It is also invisible to the naked eye. According to AIRAH DA07, the construction is still tolerable, but in case of additional and unexpected stress loads, it does not show any safety reserves against visual mould growth, spores and harmful degradation products in smaller amounts might result - the traffic light is "yellow" when the Mould Index is greater than 1 but less than 3.

A Mould Index of more than 3 represents a large area of mould growth that is clearly visible (Figure 5.9). Mould can have an influence on component safety and indoor air quality. This should be avoided: the traffic light is therefore "red".

The maximum tolerable value for MI can be found in the AIRAH DA07 Design Application Manual Criteria for Moisture Control Design Analysis in Buildings:

"In order to minimise problems associated with mould growth on the surfaces of components of building envelope assemblies, the Mould Index, [....], shall not exceed a value of three (3.00)."

pro clima recommends a MI index below 1 (green) should always be the target for healthy building design but concedes this may not always be possible in difficult sub-tropical climatic situations. See table 5.6.

5.2.4 Risk of impact on the health of occupants

"Risks associated with water vapour and condensation must be managed to minimise their impact on the health of occupants." [68]

Depending on the species, mould spores can also survive extreme conditions such as acids and alkaline, frost and heat and many chemicals. Some species can be reduced to a stand-by mode over years and decades, and can survive dry periods. When the growing conditions are suitable again (temperature and humidity) they start to germinate and grow. See Figure 5.11 & 5.12.

Spores as well as the decomposition of products from the activity of mould are toxic. They can also cause allergies, and depending on the species and the immune system, can even continue to live as mould in a human body. A mould-free building, or mould-free indoor air, is an important prerequisite for the health of humans and animals. See Figure 5.9 & 5.14.

5.3 Summary

- Steady-state calculation methods are only a rough approximation, for heat and moisture transport within constructions and can be used for illustration purposes only.
- Hygrothermal simulations with WUFI® Pro show realistic results of heat and moisture transport in building components based on climatic conditions such as temperature, humidity, wind effects, solar absorption, heat radiation, day and night cycles.
- The moisture transports in the building component layers take into account not only diffusion and convection, but also absorption and storage capacity, capillarity and evaporative cooling, etc. of materials.
- With WUFI® Pro, the moisture contents of the individual building material layers and the boundary and surface layers of the materials can be calculated.
- By calculating for any length of time over a period of years, it is possible to see whether there is an accumulating effect and a tendency towards excessively humid conditions at material layer interfaces or a stable dry condition.
- High relative humidity on the surface of individual material layers indicate the danger of mould growth with the consequence of possible structural damage and/or health impairments.
- Mould spores or their components can cause or promote allergies and/or respiratory diseases such as asthma when inhaled. It is recommended that buildings are designed and constructed with a low risk of mould to avoid causing health problems to the occupants of the building.
- The post-processor 'WUFI® Mould Index VTT' integrated in WUFI® Pro enables an analysis of the mould risk in a construction in the respective component layers and the climatic conditions inside and outside.
- The presence of organic construction dust on mineral surfaces can turn mould resistant materials into mould sensitive substrates.
- The presence of timber products in construction means it is wise to design to protect these "sensitive" materials from mould.
- The result is the so-called Mould Index (MI), displayed on a 6-point scale.
- pro clima only recommends the traffic light value green should be the targeted value at design phase, i.e. an MI value below 0-1.
- An MI <3 (yellow traffic light) is still tolerable according to AIRAH DA07, although it does not provide optimal protection against mould within the construction
- AIRAH DA07 in Australia excludes constructions with a Mould Index of more than 3.
- When greater than MI of 3, mould growth can be seen on the material surface without a microscope. There will be a negative impact on indoor air quality and consequential structural damage may occur.

Figure 5.13: Location of collected sample of damp insulation. Fungi identified from damp insulation are penicillium, Cladosporium and alternaria. [69]

Figure 5.14: Sample scraped from the side of roof truss. Fungi identified from side of truss is penicillium. [69]

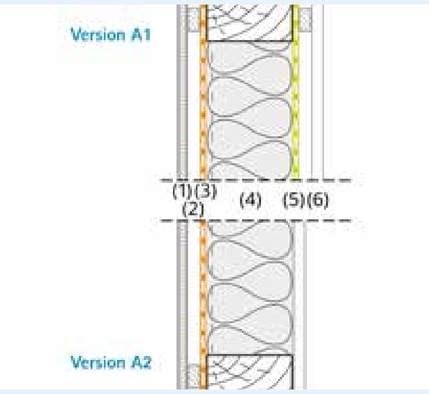


Figure 6.1: Wall construction A (1) Pre-finished fibre cement, 10 mm; (2) Drainage cavity, 20 mm; (3) Wall wrap, SOLITEX EXTASANA®; (4) Insulation, 90 mm; (5.1) No airtightness layer (A2); (5.2) Airtightness layer INTELLO® PLUS (A1); (6) Gypsum plasterboard, 10 mm

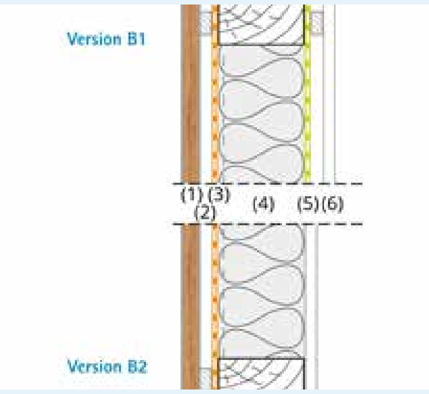


Figure 6.2: Wall construction B (1) Timber weatherboards, 19 mm; (2) Drainage cavity, 20 mm; (3) Wall wrap, SOLITEX EXTASANA®; (4) Insulation, 90 mm; (5.1) No airtightness layer (B2); (5.2) Airtightness layer INTELLO® PLUS (B1); (6) Gypsum plasterboard, 10 mm

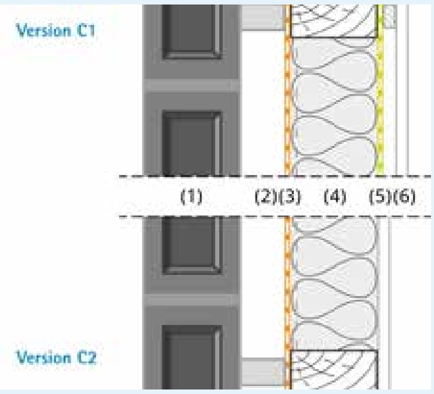


Figure 6.3: Wall construction C (1) Brickwork, 110 mm; (2) Drainage cavity, 50 mm; (3) Wall wrap, SOLITEX EXTASANA®; (4) Insulation, 90 mm; (5.1) No airtightness layer (C2); (5.2) Airtightness layer INTELLO® PLUS (C1); (6) Gypsum plasterboard, 10 mm

6. Walls

6.0 Analysis of moisture content in wall constructions in different climatic regions

The basic principles of building physics described in chapter 3 show that if the outside climate is temporarily colder than the climate inside the building, the outer wall system layers are particularly critical in terms of moisture accumulation. The air sealing and vapour control layer then needs to be placed on the inside. In Australia, this principle applies to Climate Zones 2 to 8.

In permanently warm regions, this view is reversed: If the outside climate is permanently warmer than the inside climate, the material layers on the inside of the building component (air-conditioned side) are particularly critical in terms of moisture. The airtight moisture-regulating layer must then be achieved on the outside of the insulation. In Australia, this is applicable to Climate Zone 1 tropical climates.

6.1 Boundary conditions and construction details for constructions in climate zones 2 – 8

WUFI® Pro was used for hygrothermal simulation of the moisture flows and temperature profiles in a typical lightweight wall construction with three different facade claddings in Climate Zones 2 - 7. The moisture content in the critical component layers (outer layers) was determined and any mould infestation was evaluated. For climate zone 8, the conclusions and recommendations from climate zone 7 (Hobart) are applicable.

Worst-case scenarios were used as a basis of calculations. This approach is useful and crucial in order to take into account unfavourable conditions that may regularly occur in certain risk areas of the construction.

These risk areas include, for example, building geometry effects (including corners, setbacks and overhangs) built-in components (windows and doors) and also penetrations (pipes, conduits or cables). Depending on planning and execution, so-called "unavoidable residual leakage" of moisture laden air may occur in the completed building envelope, so that it makes sense to consider further reserves for component safety.

The general principle is: if the safety reserves are sufficiently high (drying capacity), no structural damage will occur even in the event of unintended moisture loads. For this purpose, the amount of designed drying should always be higher than the moisture loads plus additional safety margins.

The simulations were based on the following general conditions:

- Orientation of the wall component to the south: Sunlight does not strike the component directly here, but only as scattered light with resulting lower heating of the exterior surface.
- Medium colouring of the facade (absorption a=0.5): 50 % of the incident sunlight is reflected, 50 % is converted into thermal energy. The heating of a lighter component surface is low compared to a dark colouring and has higher risk of moisture accumulation on the exterior layers.
- Low ventilation rate in ventilated wall cavity behinds the cladding (ventilation rate: 6.0 1/h): At windows and doors, projections and recesses, ventilation is often significantly reduced due to the lack of ventilation openings and the short rear ventilation paths - in some cases no air change is achieved at all.
- Start of the calculation on April 1 for the winter half-year: The calculation does not start with a drying phase (summer), but with a wetting phase (winter).

For the calculations, the three typical facade variants were examined.

- Construction A: Fibre cement cladding
- Construction B: Timber cladding
- Construction C: Masonry veneer

For the hygrothermal simulations, materials with measured properties from the North American database and from the Fraunhofer Institute for Building Physics, Germany were used. These were the best match to local Australian materials. (Figure 6.1)

6.1.1 Construction details of the walls

From outside to inside:

- Wall cladding
  - Construction A: Fibre cement cladding, 10 mm
  - Construction B: Timber cladding, 20 mm
  - Construction C: Masonry veneer, 110 mm
- Drainage cavity, ventilation rate: 6,0 air changes per hour
  - Construction A and B: 20 mm cavity
  - Construction C: 50 mm cavity
- Weather Resistive Barrier, according to requirements SOLITEX EXTASANA®
- Glass wool, 90 mm (R2.7 batts)
- Airtight construction (AIRAH DA07 threshold)
- Version 1: Without planned and without executed air barrier system

- Version 2: With planned and executed INTELLO® PLUS Intelligent airtightness and vapour control layer.
- Service cavity, 40 mm
- Gypsum plasterboard, 10 mm

6.1.2 Environmental conditions and locations

For this study, the following cities were selected for each climate zone.
Outdoor climate:

- Climate zone 7: Hobart and Canberra
- Climate zone 6: Melbourne
- Climate zone 5: Sydney, Adelaide, Perth
- Climate zone 4: Mildura
- Climate zone 3: Alice Springs
- Climate zone 2: Brisbane
- Climate zone 1: Darwin

The climate data were provided by Meteonorm, a global climate database. The climate datasets include hourly data for:

- Temperature [°C]
- Relative humidity [%]
- Radiation [W/m²]
- Wind speed [m/s]
- Precipitation [mm]

The indoor climate was determined on the basis of AIRAH DA07 and depends, among other things, on the volume of the building, the number of bedrooms, and the building services with regard to ventilation and exhaust.
Parameters for indoor climate according to AIRAH DA07:

- Building volume: 10 m length x 10 m width x 2.4 m floor height x 2 level = 480 m³
- Numbers of bedrooms: 3
- AC Type: Air-conditioning with cooling
- Air Exchange Rate (AER): 0.2 when no IAB is present (Def. Standard, AIRAH DA07)
  - Including air transported water vapour into the construction @ 5 m³/(h.m²) & 8 m stack height using IBP air infiltration model.
- Air Exchange Rate (AER): 0.1 when INTELLO PLUS® is present (Def. Airtight, AIRAH DA07)
- Including air transported water vapour into the construction @ 3 m³/(h.m²) & 8 m stack height using IBP air infiltration model.

6.1.3 Layers critical to building physics with the risk of condensation

In a cool and damp external climate, the material layers on the outside of a structure tend to increase in moisture. This is especially true if the outer component layers

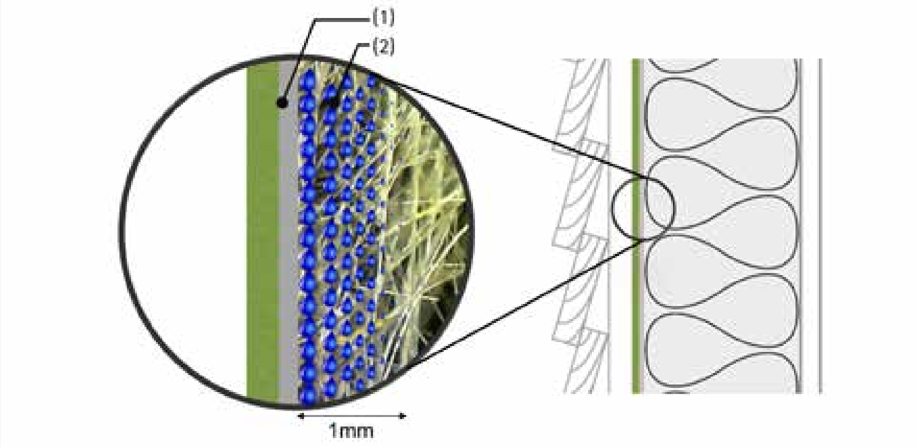


Figure 6.4: The combination of diffusion inhibiting Weather Resistive Barriers and smooth non-porous surfaces provide entrapment of water vapour and a condensation plane for water vapour to the extent that liquid condensate run-off is probable in many climates. (1) Non-porous surface, no moisture buffering; (2) 1 mm mineral fibre moisture capacity, 329 g/m²

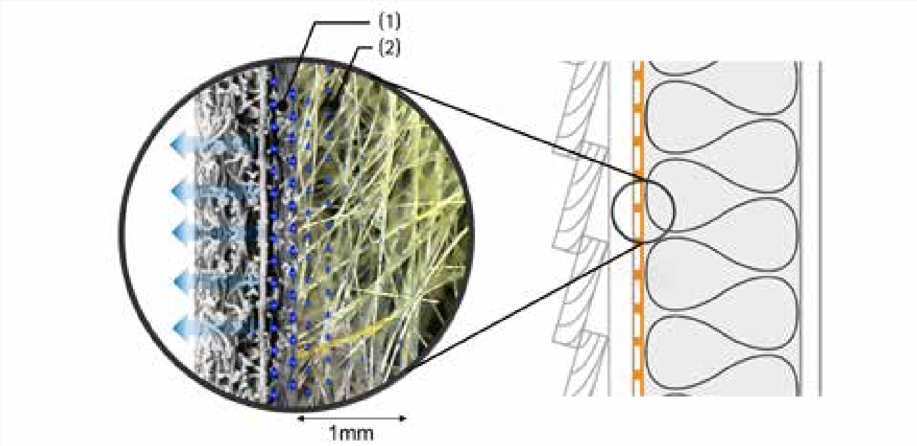


Figure 6.5: Vapour permeable Weather Resistive Barriers reduce the risk of entrapment of water vapour. The back fleece provides mechanical protection and also provides additional hygric capacity to reduce the risk of run-off in cold snaps in cold climates. Vapour permeable membranes will still have some vapour resistance and high humidity behind the membrane is possible and may require the use of an internally located intelligent vapour control layer depending on the climate and building occupancy. (1) Fleece 55 g/m² moisture buffering; (2) 1 mm mineral fibre moisture capacity, 329 g/m²

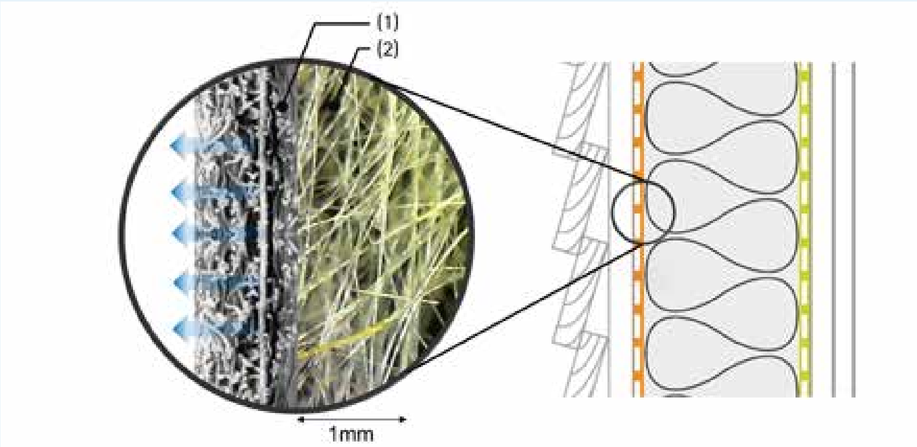


Figure 6.6: The use of internally located vapour control layers are necessary to eliminate the risk of high humidity for prolonged periods of time consequently leading to proliferation of mould spores. (1) Fleece 55 g/m² moisture buffering; (2) 1 mm mineral fibre moisture capacity, 329 g/m²

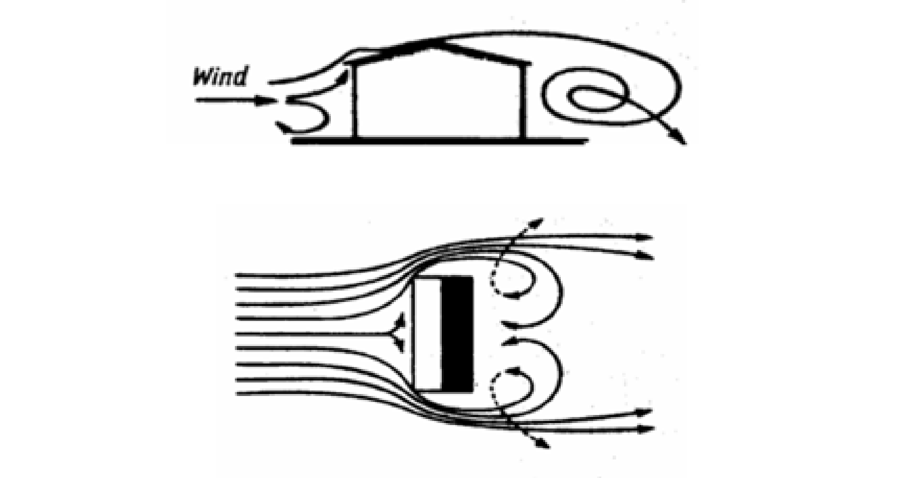


Figure 6.7: Air pressure differentials depend on wind speed and direction, topography, neighbouring buildings, building height and geometry. Wind effects are neglected because changing direction leads to alternating condensation & drying processes, wind blows only temporarily, strong wind turns some moisture leaks into energy leaks.

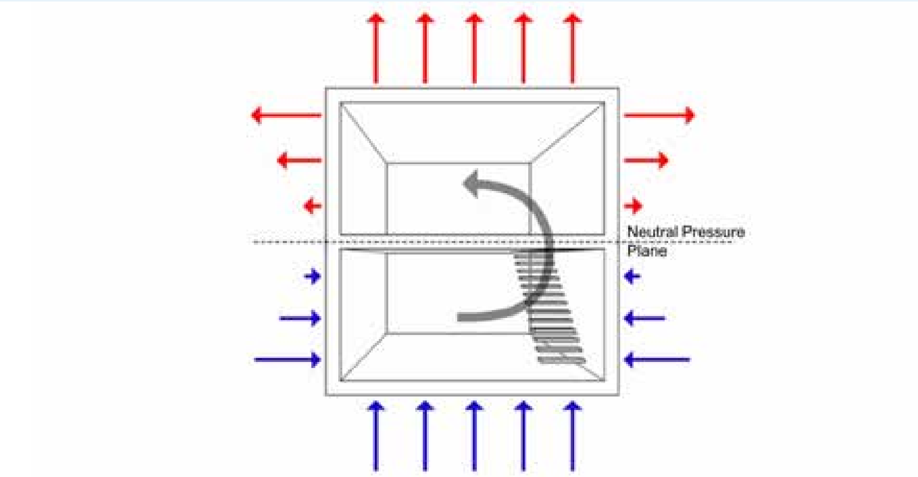


Figure 6.8: Overpressure depends on temperature difference between indoors and outdoors & the height of connected indoor air volume. Roofs and upper-level walls experience positive pressure and air transported water vapour by convection through envelope imperfections.

are diffusion-inhibiting or even diffusion-tight. Then the moisture coming from the inside, either by vapour diffusion (material permeability) or by convection (air flow) can condense in or on the layer. The outer layers obstruct the flow of moisture moving from the inside to the outside and can cause moisture to accumulate. Resulting condensate and/or elevated humidity leads to an increased risk of mould (Figures 6.4 – 6.6).

At lower outdoor temperatures compared to the indoor temperature, permeability class 4 membranes with their high vapour permeability on the outside offer the advantage of allowing some of the vapour generated to dry out (pass) to the outside. The TEEE membrane with its active moisture management has the further advantage that it actively transports moisture to the outside along the molecular chains (see chapter 4) and not only via an otherwise usual air flow (convection) through pores.

When analysing the moisture situation of a component, a distinction is made between surface moisture (condensation & high humidity) and material moisture within the pores of a porous substrate. Material moisture can lead to structural damage, surface moisture to mould on the surfaces.

Diffusion-inhibiting or even diffusion-tight material layers such as aluminium foil on the outside block drying to the outside and very quickly become moisture and condensation traps (see chapter 7).

Protection against the entry of diffusion and convection moisture is provided by an air sealing layer with intelligent vapour control applied to the inside of the thermal insulation.

For the analysis of the moisture situation in the construction, the moisture content of the outer 1 mm thick thermal insulation layer is calculated. A capillary-active material like glass wool in contact with water will take up this water until it reaches its free saturation wf. This water content wf corresponds to the moisture storage function at a relative humidity of 100 %.

Up to 329 kg/m^3 can be held within the fibre structure of the glass fibre insulation of density 21 kg/m^3 at free saturation, which occurs at 100 % RH. This is typical glass wool density used in high performance R2.5 – R2.7 batts in Australia. For a 1 mm thick layer this equates to 329 g/m^2 of liquid formation on an area basis as a threshold before liquid condensate may start to run down the back of a non-absorptive aluminium foil membrane. The run-off capacity is increased by 55 g/m^2 the fleece on the back side

of triple layer vapour permeable membrane technology.
However, just because there may be no liquid condensate run-off does not mean there is not a problem. The health risk is indicated with time dependent temperature and relative humidity at the point behind the Weather Resistive Barrier which is used to calculate the Mould Index in accordance with AIRAH DA07 Hygrothermal Design Criteria for Moisture Analysis of Buildings. It is possible to get no condensate run-off but still have risk of mould.

6.1.5 Layers critical to building physics with the risk of mould

High relative humidity can lead to mould growth on material surfaces. In climate zones 2 - 8, the main humidification takes place in the outer layers of the building components between materials of different vapour diffusivity properties. This is known as the critical location. Here, there is a risk of mould growth. For analysis purposes, the Mould Index (MI) as defined in AIRAH DA07 is calculated with the VTT model of the WUFI® Pro on the outer surface of the mineral fibre insulation (see chapter 5.2.2).
Optimal is a MI below 1. Then the MI traffic light is green and no mould growth is to be expected. With an MI between 1 and 3, the MI traffic light shows yellow. Mould growth is emerging or occurring. Some of the mould growth is already visible to the eye. An MI above 3 indicates visually detectable mould growth. The traffic light is red. Constructions with an MI above 3 are considered highly critical and should be avoided. In this case, severe damage to the building substance and a high health risk to the occupants or users of the building is to be expected.

6.2 Evaluation of different wall constructions

The following wall constructions are compared:
- Version 1: Without a dedicated air sealed intelligent vapour control layer on the inside.
- Version 2: With INTELLO® PLUS air sealing and vapour control layer with intelligent moisture management on the inside.

On the outside of all constructions there is SOLITEX EXTASANA® with a diffusion resistance of 0.5 MNs/g.
The moisture content and Mould Index of the outer 1 mm of mineral fibre insulation is determined in the constructions at the respective locations. Knowing the moisture content in the outer layers allows the risk of liquid-run off to be assessed. In the context of scenarios with high accumulation run-off is possible above 329 g/m² for non-absorptive foil layers and 384 g/m² (including membrane fleece) calculated across the 1 mm layer.
The moisture flows are based on diffusion calculations with additional convective moisture loads simulated, assuming a quantity of air transported water vapour indicative of a non-perfect airtightness of 5 $m^3/(m^2{\cdot}h)$. Tighter buildings will reduce the influence of this additional air transported water vapour into the structure and improve the overall result.
For the structures without a planned intelligent air and water vapour control layer, the moisture loads are likely to be higher than the results of the calculations show, since the convection currents can allow more moisture to infiltrate than can be simulated.

As a result, higher mould growth could also occur than is indicated by the simulation.
In regions with a lot of wind, excess pressure on the side of buildings facing the wind can cause the wind to penetrate exterior-air-tight structures. This is usually not critical in terms of humidity, since in winter climates the cold outside air has a low absolute water content and has a drying effect. On the downwind side (leeward) of buildings, on the other hand, warm air containing moisture is sucked from inside to outside of the building by negative pressure in exterior-airtight constructions. This leeward side effect is critical for the construction or for the materials it contains in terms of moisture, since the warm, moist air from the interior cools down in the process and a high level of condensation can occur, e.g. due to the flow paths in the building component (moisture gap, see chapter 2.3). This can result in more moisture than the calculation result of the hygrothermal simulation represents if the wind predominantly blows from a single direction. The result is higher mould growth on the affected building material surfaces and in the building components. Figures 6.4 – 6.5
Safe constructions need well planned and functional airtightness layers. Airtightness must be planned during the design of a building assembly and also correctly executed on the construction site or during factory prefabrication. Checking the airtightness level by means of a Blower Door test (see Chapter 8), before the interior cladding is applied, makes it possible to detect leaks and seal them with a suitable adhesive tape, e.g. pro clima TESCON® VANA with the water-resistant adhesive or flexible and durable adhesive such as ORCON® CLASSIC.

6.2.1 Climate Zone 7 (according to climate zone 8): Hobart and Canberra

Due to the very low temperatures in winter, extraordinarily high moisture contents occur in the outer component layers in Climate Zone 7 (reference locations Hobart and Canberra) and a similar result would be expected in climate zone 8 in the case of exterior-airtight WRB constructions. These results are due to large temperature differentials between the inhabited, heated indoor space and the outdoor climate. In the outer 1 mm of glass wool insulation considered for the evaluation, depending on the construction a formation of up to 430 g/m² of condensate is predicted.

Climate Zone 7 results with an exterior-airtightness layer indicate a high likelihood of pronounced structural damage. The threshold of 384 g/m² is exceeded and condensate will likely drain by gravity during the coldest parts of the year. In the fibre cement case liquid water run-off cannot be excluded and moisture accumulation in the timber bottom plate of the wall is possible with associated structural damage. The thickness and low conductivity of timber weatherboards provide a slight insulation layer keeping the Weather Resistive Barrier (WRB) slightly warmer and reducing the formation of condensate to levels where run-off is not expected. Brick veneer, thermal buffering due to the thermal capacity of the bricks helps in the same way to keep the membrane warmer & consequently reduce condensate formation. The Mould Index of 5.3 is well above the maximum permissible limit of 3 for both the fibre cement and weatherboard claddings. This happens rapidly within the first or second winter seasons of habitation. This indicates that very favourable conditions for mould growth have been created. In addition to the risk of deterioration of the building fabric, the occupants are exposed to a significant health risk from mould and MVOCs.

An airtight construction using an Intelligent Air Barrier on the inside of the construction reduces the moisture content in all cases within the outer 1 mm of the glass wool insulation to well and truly below critical levels. The construction systems under consideration then prove to be very robust. They maintain drying capacity while limiting wetting from internal water vapour migration. These systems have high safety margins protecting against perverse health outcomes and structural damage. If necessary, they are still able to cope with further unforeseen moisture sources such as high occupancy levels or poor ventilation scenarios.

With the INTELLO® PLUS intelligent airtightness system on the inside the Mould Index remains below 1 in all cases. The Mould Index risk is green, the risk of mould is completely eliminated. The occupants or users of the building can live and work in an environment that will not be exposed to toxins from mould.

For constructions with INTELLO® PLUS intelligent airtightness system in Climate Zone 7 (and correspondingly Climate Zone 8), Hobart and Canberra show:

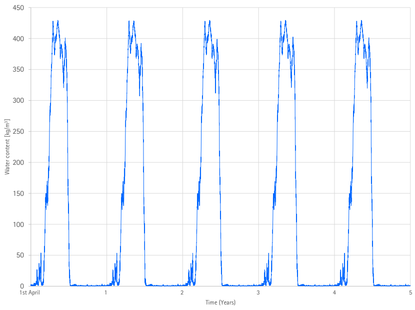
- Very low moisture content within the outer 1 mm of the mineral fibre insulation in the winter half-year of < 3.0 kg/m³. This does not pose a risk to the structure.
- a Mould Index of less than 1 (green light). The results do not suggest any mould growth, not even microscopically invisible. In addition, there is no risk to structural strength of the building and no risk to the health of the occupants and users of the buildings.

Hobart

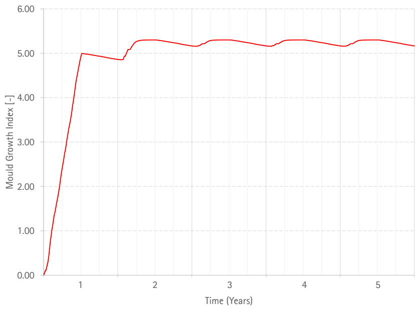
Construction A: Fibre cement cladding

A1: Construction sealed at WRB only

Condensate in the outer 1 mm insulation layer: The moisture content of the outer 1 mm insulation layer is 430 kg/m³, equivalent to 430 g/m².

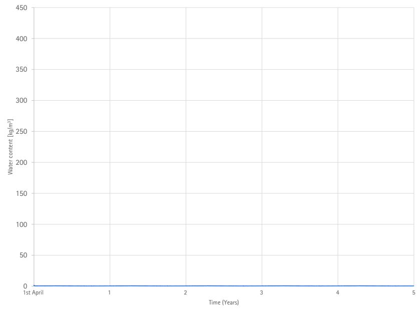


Mould Index of the outer surface of the insulation layer: The Mould Index of the outer surface of the insulation layer is 5.3.

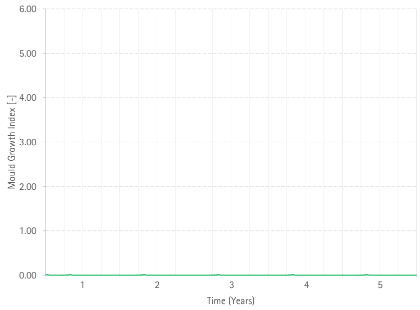


A2: Sealed WRB & INTELLO® PLUS Intelligent Air Barrier System

Condensate in the outer 1 mm insulation layer: The moisture content of the outer 1 mm insulation layer remains very low with the installation of INTELLO® PLUS.



Mould Index of the outer surface of the insulation layer: The Mould Index of the outer surface of the insulation layer is below 1.

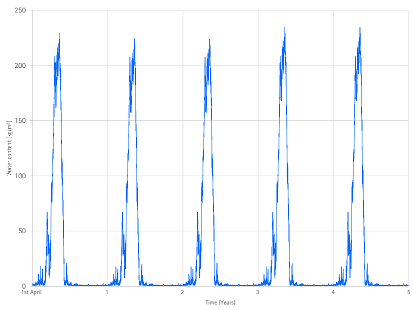


Hobart

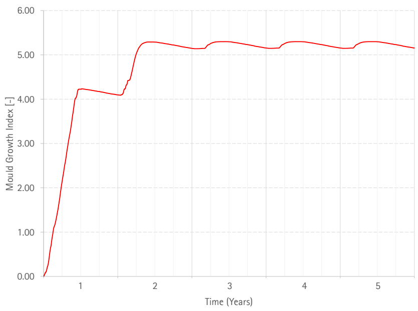
Construction B: Timber cladding

B1: Construction sealed at WRB only

Condensate in the outer 1 mm insulation layer: The moisture content of the outer 1 mm insulation layer is 235 kg/m³, equivalent to 235 g/m².

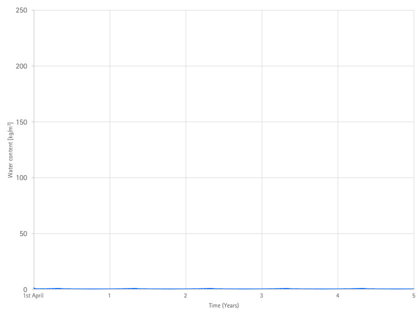


Mould Index of the outer surface of the insulation layer: The Mould Index of the outer surface of the insulation layer is 5.3.

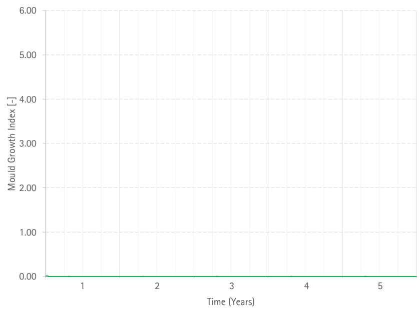


B2: Sealed WRB & INTELLO® PLUS Intelligent Air Barrier System

Condensate in the outer 1 mm insulation layer: The moisture content of the outer 1 mm insulation layer remains very low with the installation of INTELLO® PLUS.



Mould Index of the outer surface of the insulation layer: The Mould Index of the outer surface of the insulation layer is below 1.

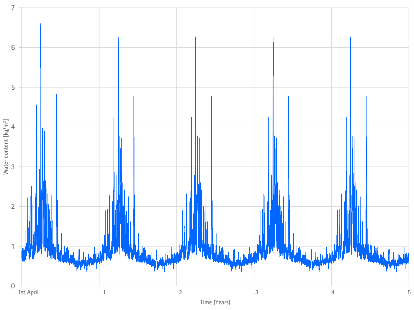


Hobart

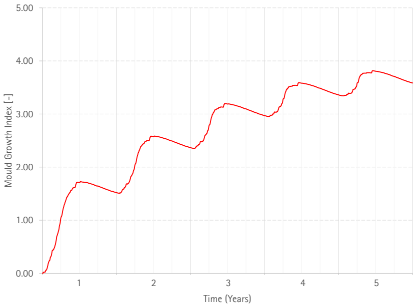
Construction C: Masonry veneer

C1: Construction sealed at WRB only

Condensate in the outer 1 mm insulation layer: The moisture content of the outer 1 mm insulation layer is 7 kg/m³, equivalent to 7 g/m².

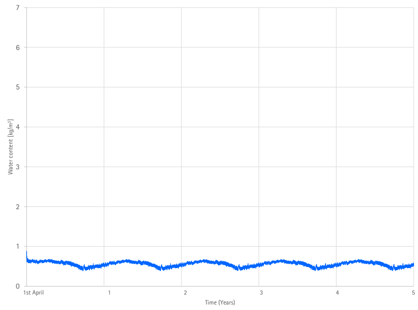


Mould Index of the outer surface of the insulation layer: The Mould Index of the outer surface of the insulation layer is 3.82.

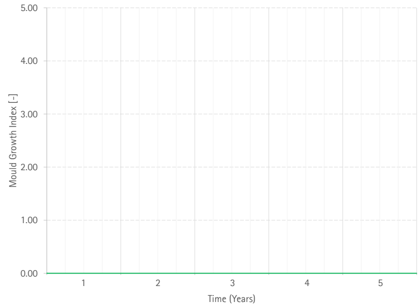


C2: Sealed WRB & INTELLO® PLUS Intelligent Air Barrier System

Condensate in the outer 1 mm insulation layer: The moisture content of the outer 1 mm insulation layer remains very low with the installation of INTELLO® PLUS.



Mould Index of the outer surface of the insulation layer: The Mould Index of the outer surface of the insulation layer is below 1.

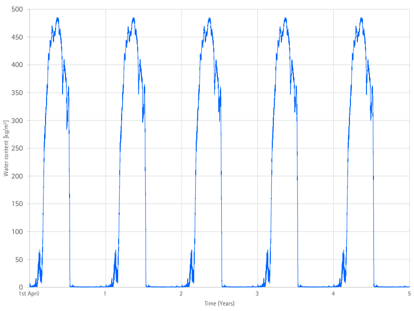


Canberra

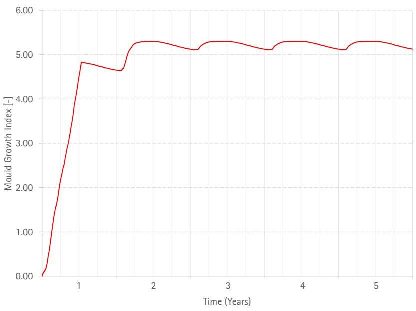
Construction A: Fibre cement cladding

A1: Construction sealed at WRB only

Condensate in the outer 1 mm insulation layer: The moisture content of the outer 1 mm insulation layer is 485 kg/m³, equivalent to 485 g/m².

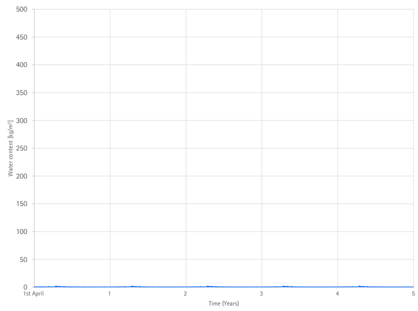


Mould Index of the outer surface of the insulation layer: The Mould Index of the outer surface of the insulation layer is 5.3.

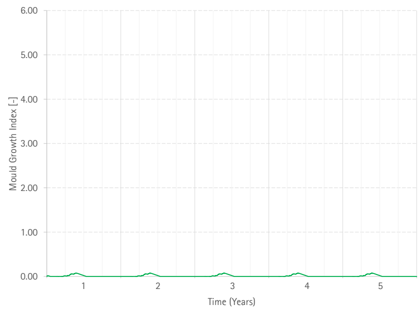


A2: Sealed WRB & INTELLO® PLUS Intelligent Air Barrier System

Condensate in the outer 1 mm insulation layer: The moisture content of the outer 1 mm insulation layer remains very low with the installation of INTELLO® PLUS.



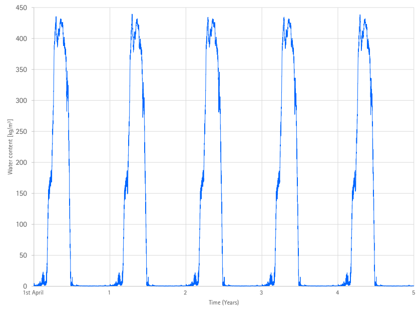
Mould Index of the outer surface of the insulation layer: The Mould Index of the outer surface of the insulation layer is below 1.



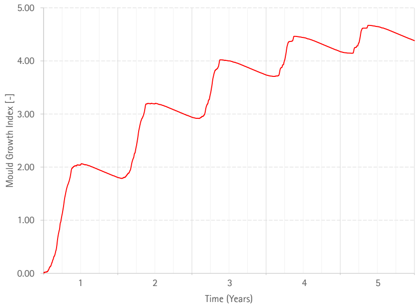
Canberra
Construction B: Timber cladding

B1: Construction sealed at WRB only

Condensate in the outer 1 mm insulation layer: The moisture content of the outer 1 mm insulation layer is 439 kg/m³, equivalent to 439 g/m².

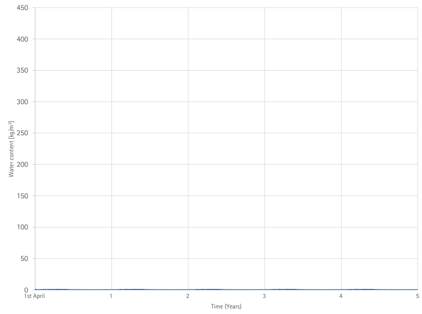


Mould Index of the outer surface of the insulation layer: The Mould Index of the outer surface of the insulation layer is 5.3.

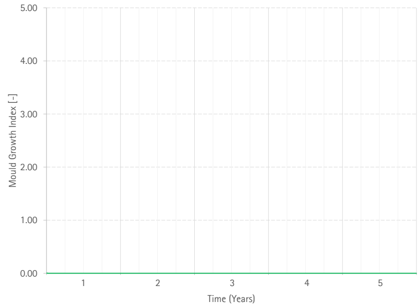


B2: Sealed WRB & INTELLO® PLUS Intelligent Air Barrier System

Condensate in the outer 1 mm insulation layer: The moisture content of the outer 1 mm insulation layer remains very low with the installation of INTELLO® PLUS.



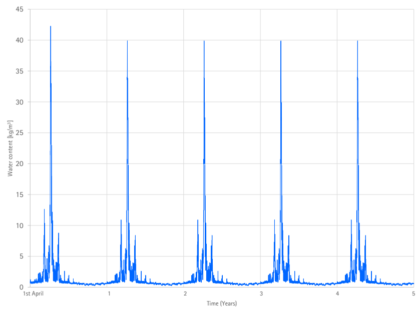
Mould Index of the outer surface of the insulation layer: The Mould Index of the outer surface of the insulation layer is below 1.



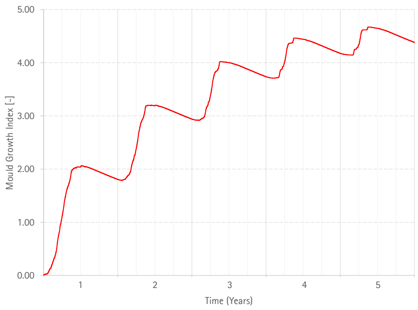
Canberra
Construction C: Masonry veneer

C1: Construction sealed at WRB only

Condensate in the outer 1 mm insulation layer: The moisture content of the outer 1 mm insulation layer is 42 kg/m³, equivalent to 42 g/m².

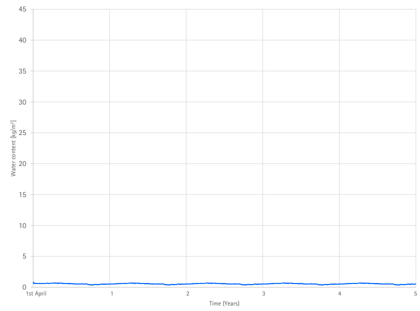


Mould Index of the outer surface of the insulation layer: The Mould Index of the outer surface of the insulation layer is 4.67.

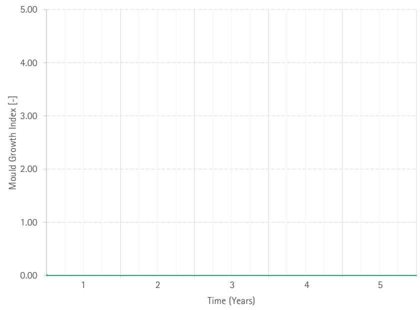


C2: Sealed WRB & INTELLO® PLUS Intelligent Air Barrier System

Condensate in the outer 1 mm insulation layer: The moisture content of the outer 1 mm insulation layer remains very low with the installation of INTELLO® PLUS.



Mould Index of the outer surface of the insulation layer: The Mould Index of the outer surface of the insulation layer is below 1.



6.2.2 Climate Zone 6: Melbourne

Climate Zone 6 is represented by the Melbourne location (see chap. 3.2.3). For the analysed constructions with fibre cement cladding, timber cladding and brick veneer exterior, moisture contents up to 432 kg/m³ are predicted in the exterior 1mm glass wool insulation with exterior wind tight WRB layers. This corresponds to a water quantity up to 432 g/m². This amount of moisture cannot be held by the glass wool, so the water runs off downwards with gravity. In fibre cement clad cases in climate zone 6 run-off cannot be excluded and moisture accumulation in the timber bottom plate of the wall is possible. The thickness and low conductivity of timber weatherboards provide a slight insulation layer keeping the WRB slightly warmer and reducing the formation of condensate to levels where run-off is not expected. Brick veneer, thermal buffering due to the thermal capacity of the bricks helps in the same way to keep the membrane warmer & consequently reduce condensate formation.

Building damage is expected in the fibre cement case. In the long term, high levels of material moisture led to the decomposition of the building fabric and even endanger the structural load-bearing capacity. They should therefore be avoided at all costs.

A resulting Mould Index of 5.3 is determined in all exterior-airtight lightweight clad cases the limit of 3, at which visible mould growth occurs, is clearly exceeded. The Mould Index is therefore red. The red colour indicates that clearly visible mould growth is expected. Moulds or their components, such as the mycelium, have a significant impact on the health of occupants and users of infested buildings.

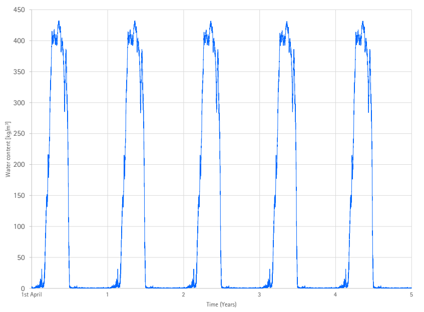
If the construction in Climate Zone 6 is airtight on the inside and equipped with INTELLO® PLUS intelligent airtightness system, the moisture content in the outer layer of the glass wool insulation is negligible. In 1mm of the thermal insulation, there is a maximum condensate of only 1.6 g/m² (1.6 kg/m³). This can be temporarily stored by the membrane inner fleece during the cold nights and is released again when temperature rises – the risk of moisture damage is therefore removed. The construction has high drying capacity providing additional safety that protects the occupants and users from the risk of mould growth and the structural framing from damage.

Melbourne

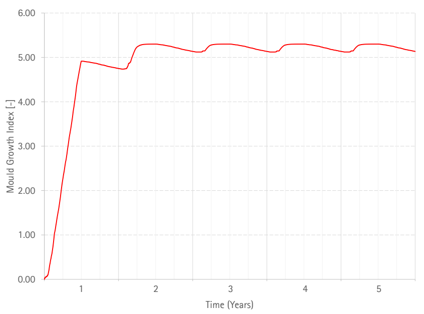
Construction A: Fibre cement cladding

A1: Construction sealed at WRB only

Condensate in the outer 1mm insulation layer: The moisture content of the outer 1mm insulation layer is 432 kg/m³, equivalent to 432 g/m².

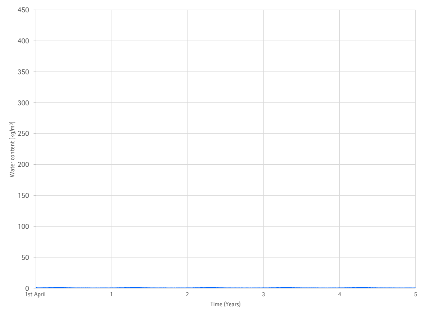


Mould Index of the outer surface of the insulation layer: The Mould Index of the outer surface of the insulation layer is 5.3.

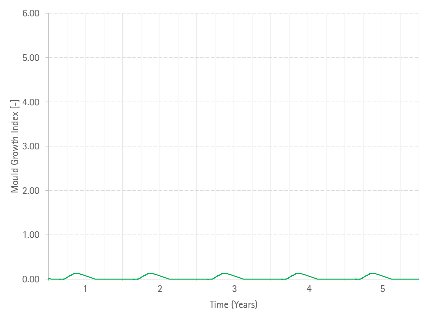


A2: Sealed WRB & INTELLO® PLUS Intelligent Air Barrier System

Condensate in the outer 1mm insulation layer: The moisture content of the outer 1mm insulation layer remains very low with the installation of INTELLO® PLUS.



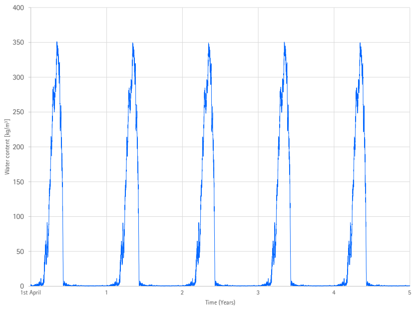
Mould Index of the outer surface of the insulation layer: The Mould Index of the outer surface of the insulation layer is below 1.



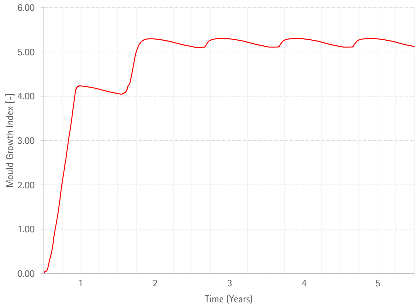
Melbourne
Construction B: Timber cladding

B1: Construction sealed at WRB only

Condensate in the outer 1 mm insulation layer: The moisture content of the outer 1 mm insulation layer is 351 kg/m³, equivalent to 351 g/m².

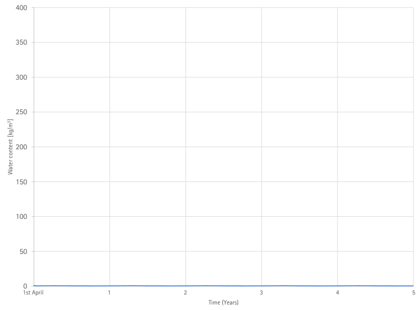


Mould Index of the outer surface of the insulation layer: The Mould Index of the outer surface of the insulation layer is 5.3.

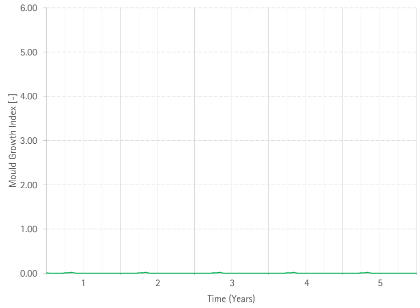


B2: Sealed WRB & INTELLO® PLUS Intelligent Air Barrier System

Condensate in the outer 1 mm insulation layer: The moisture content of the outer 1 mm insulation layer remains very low with the installation of INTELLO® PLUS.



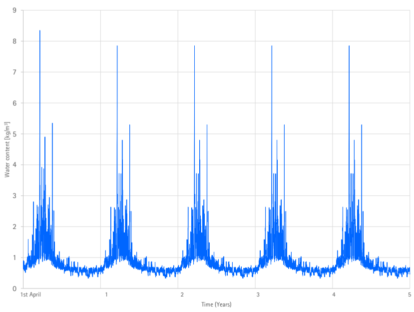
Mould Index of the outer surface of the insulation layer: The Mould Index of the outer surface of the insulation layer is below 1.



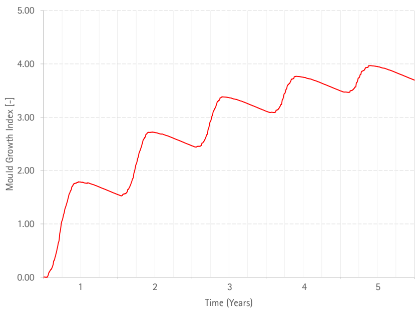
Melbourne
Construction C: Masonry veneer

C1: Construction sealed at WRB only

Condensate in the outer 1 mm insulation layer: The moisture content of the outer 1 mm insulation layer is 8 kg/m³, equivalent to 8 g/m².

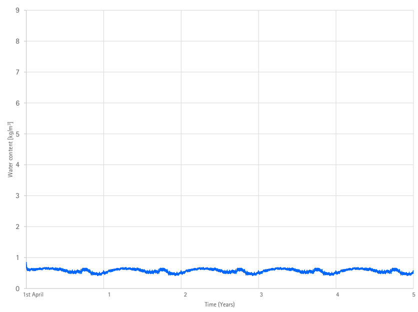


Mould Index of the outer surface of the insulation layer: The Mould Index of the outer surface of the insulation layer is 3.97.

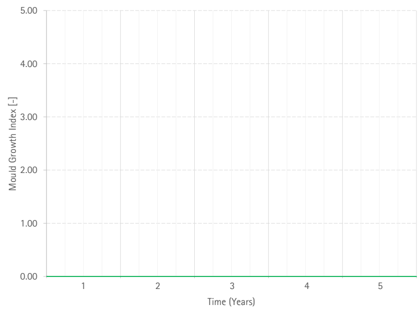


C2: Sealed WRB & INTELLO® PLUS Intelligent Air Barrier System

Condensate in the outer 1 mm insulation layer: The moisture content of the outer 1 mm insulation layer remains very low with the installation of INTELLO® PLUS.



Mould Index of the outer surface of the insulation layer: The Mould Index of the outer surface of the insulation layer is below 1.



6.2.3 Climate Zone 5: Adelaide, Sydney and Perth

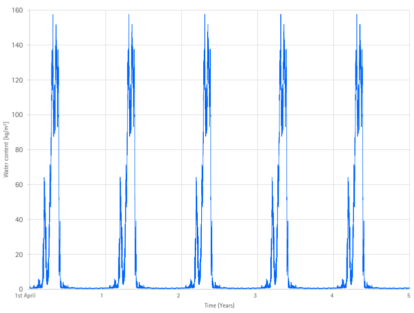
Sydney, Adelaide and Perth represent Climate Zone 5 (see chap. 3.2.4). If a timber construction with exterior-airtight WRB is planned and executed in this climate, high humidity in the outer component layers should be expected. These can lead to mould growth based on the duration of time high humidity is present. WUFI® Pro simulations show moisture contents between 3 and 287 kg/m³ in the winter half-year. These occur in the outer 1 mm of the glass wool insulation. It is not expected that condensate run-off will occur because the glass wool and back fleece can hold up to 384 g/m².
The brick veneer construction presents a comparatively low moisture content in the outer layers with a resulting 3, 5 & 4 kg/m³ in Adelaide, Sydney & Perth respectively. The thermal inertia of the brick outer skin helps to dampen the temperature minimums reducing the frequency of condensation within the 1 mm glass wool layer. The moisture content is non-critical for run-off but provides sufficiently humid conditions for mould to progressively accumulate over several winter seasons and reach critical levels after 5 years of beyond.
With regard to the mould assessment, the constructions with fibre cement cladding and timber cladding quickly reached a Mould Index near 5 after 2-5 years of habitation. In the case of the brick veneer component, the Mould Index increases more slowly, but after 5 years reaching a Mould Index in the vicinity of 2.5 with an upward trend. Thus, visible mould is to be expected with all constructions eventually. Clearly visible mould growth is already regarded as having adverse health effects on the occupants, in addition to high remediation costs. The Mould Index can be considered a dark yellow as it approaches red eventually.
If, on the other hand, constructions are planned correctly and Intelligent Air Barriers are executed in a professional manner, there is no danger of perverse health consequences. Constructions equipped with the INTELLO® PLUS intelligent airtightness system have near zero moisture contents (≤ 1,10 kg/m³) in the outer 1 mm of the glass wool insulation. These are non-critical levels and prevent the growth of mould with absolute certainty. The Mould Index of less than 1 indicts a robust component that does not endanger the health of occupants and users through mould growth and MVOCs. Structures that remain dry have excellent longevity and indoor conditions remain healthy.
The inner city living in the Sydney East region was assumed to have a reduced dwelling footprint area, assumed to be 114 m² with a total volume of 274 m³ based on ABS data 2018 for an average townhouse.

Adelaide

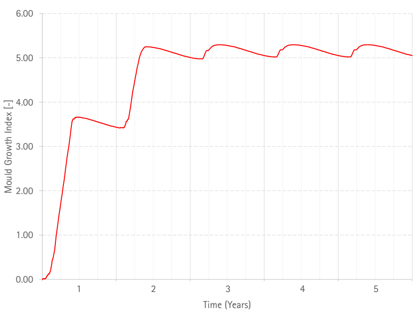
Construction A: Fibre cement cladding

A1: Construction sealed at WRB only

Condensate in the outer 1 mm insulation layer: The moisture content of the outer 1 mm insulation layer is 158 kg/m³, equivalent to 158 g/m².

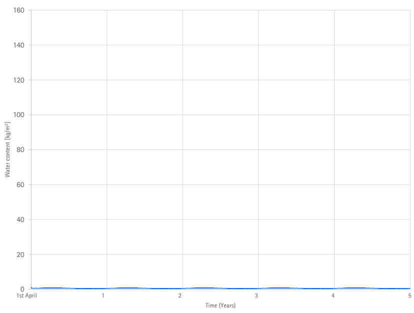


Mould Index of the outer surface of the insulation layer: The Mould Index of the outer surface of the insulation layer is 5.3.

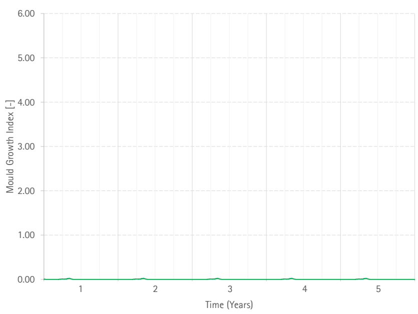


A2: Sealed WRB & INTELLO® PLUS Intelligent Air Barrier System

Condensate in the outer 1 mm insulation layer: The moisture content of the outer 1 mm insulation layer remains very low with the installation of INTELLO® PLUS.



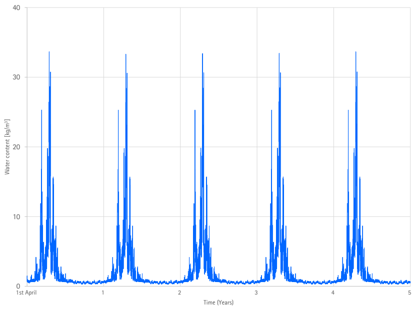
Mould Index of the outer surface of the insulation layer: The Mould Index of the outer surface of the insulation layer is below 1.



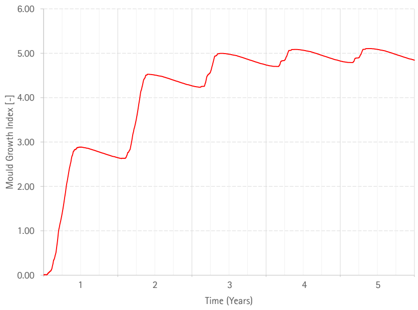
Adelaide
Construction B: Timber cladding

B1: Construction sealed at WRB only

Condensate in the outer 1 mm insulation layer: The moisture content of the outer 1 mm insulation layer is 34 kg/m³, equivalent to 34 g/m².

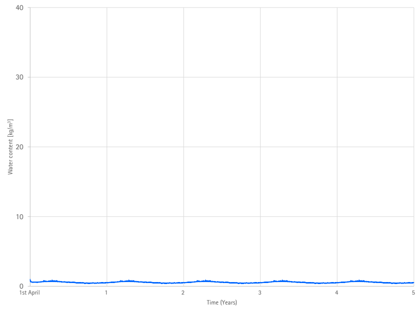


Mould Index of the outer surface of the insulation layer: The Mould Index of the outer surface of the insulation layer is 5.11.

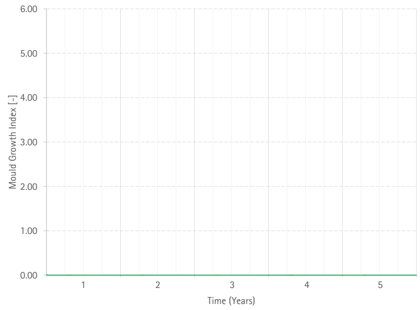


B2: Sealed WRB & INTELLO® PLUS Intelligent Air Barrier System

Condensate in the outer 1 mm insulation layer: The moisture content of the outer 1 mm insulation layer remains very low with the installation of INTELLO® PLUS.



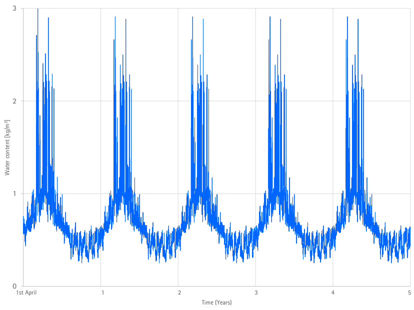
Mould Index of the outer surface of the insulation layer: The Mould Index of the outer surface of the insulation layer is below 1.



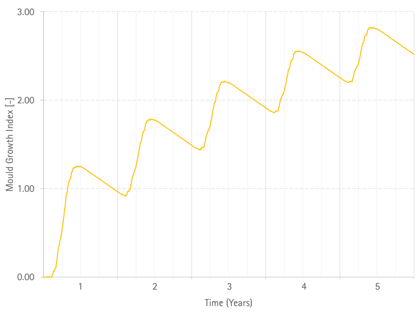
Adelaide
Construction C: Masonry veneer

C1: Construction sealed at WRB only

Condensate in the outer 1 mm insulation layer: The moisture content of the outer 1 mm insulation layer is 3 kg/m³, equivalent to 3 g/m².

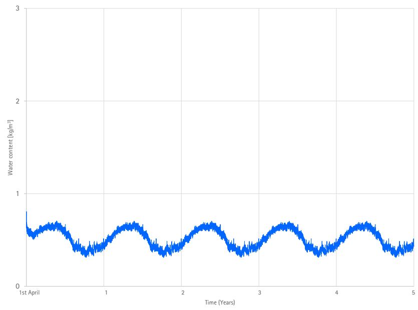


Mould Index of the outer surface of the insulation layer: The Mould Index of the outer surface of the insulation layer is 2.82.

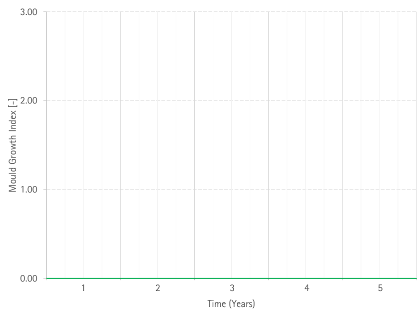


C2: Sealed WRB & INTELLO® PLUS Intelligent Air Barrier System

Condensate in the outer 1 mm insulation layer: The moisture content of the outer 1 mm insulation layer remains very low with the installation of INTELLO® PLUS.



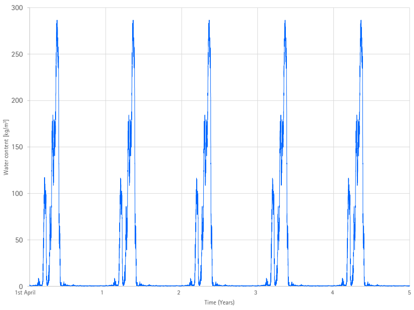
Mould Index of the outer surface of the insulation layer: The Mould Index of the outer surface of the insulation layer is below 1.



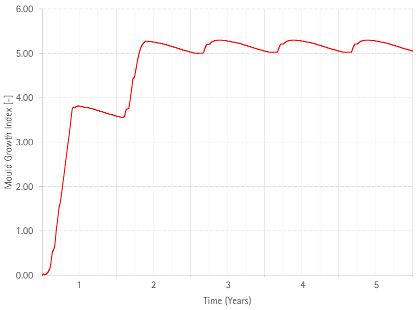
Sydney
Construction A: Fibre cement cladding

A1: Construction sealed at WRB only

Condensate in the outer 1 mm insulation layer: The moisture content of the outer 1 mm insulation layer is 287 kg/m³, equivalent to 287 g/m².

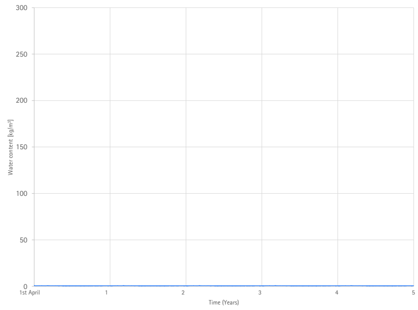


Mould Index of the outer surface of the insulation layer: The Mould Index of the outer surface of the insulation layer is 5.3.

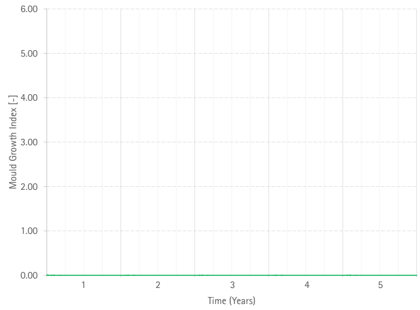


A2: Sealed WRB & INTELLO® PLUS Intelligent Air Barrier System

Condensate in the outer 1 mm insulation layer: The moisture content of the outer 1 mm insulation layer remains very low with the installation of INTELLO® PLUS.



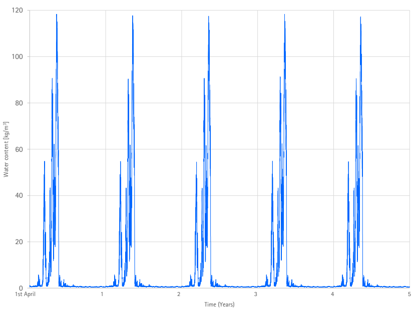
Mould Index of the outer surface of the insulation layer: The Mould Index of the outer surface of the insulation layer is below 1.



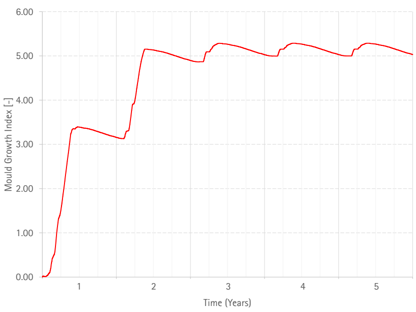
Sydney
Construction B: Timber cladding

B1: Construction sealed at WRB only

Condensate in the outer 1 mm insulation layer: The moisture content of the outer 1 mm insulation layer is 118 kg/m³, equivalent to 118 g/m².

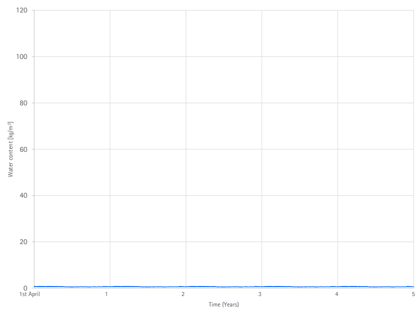


Mould Index of the outer surface of the insulation layer: The Mould Index of the outer surface of the insulation layer is 5.29.

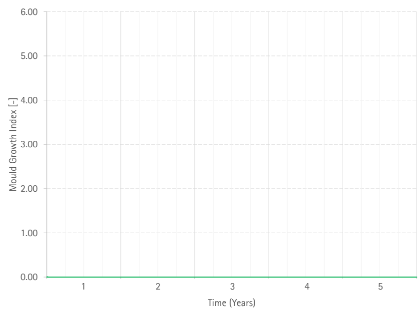


B2: Sealed WRB & INTELLO® PLUS Intelligent Air Barrier System

Condensate in the outer 1 mm insulation layer: The moisture content of the outer 1 mm insulation layer remains very low with the installation of INTELLO® PLUS.



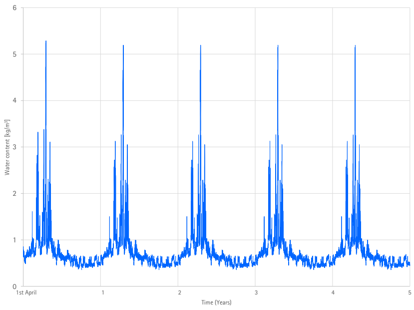
Mould Index of the outer surface of the insulation layer: The Mould Index of the outer surface of the insulation layer is below 1.



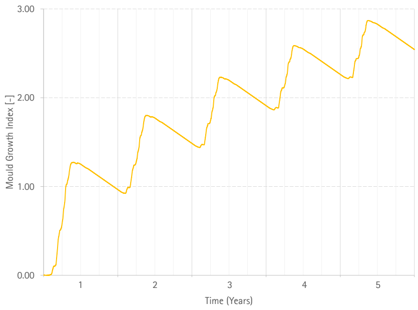
Sydney
Construction C: Masonry veneer

C1: Construction sealed at WRB only

Condensate in the outer 1 mm insulation layer: The moisture content of the outer 1 mm insulation layer is 5 kg/m³, equivalent to 5 g/m².

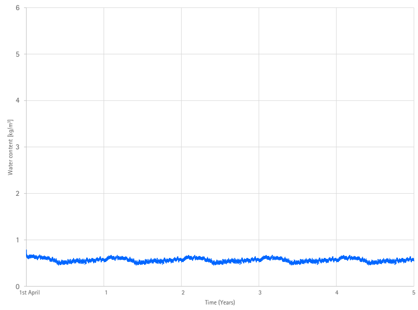


Mould Index of the outer surface of the insulation layer: The Mould Index of the outer surface of the insulation layer is 2.87.

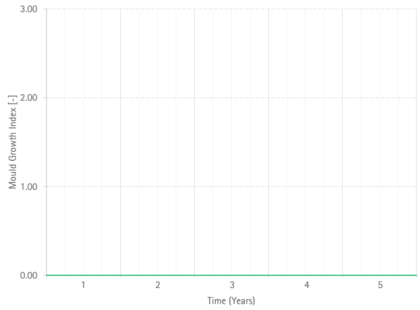


C2: Sealed WRB & INTELLO® PLUS Intelligent Air Barrier System

Condensate in the outer 1 mm insulation layer: The moisture content of the outer 1 mm insulation layer remains very low with the installation of INTELLO® PLUS.



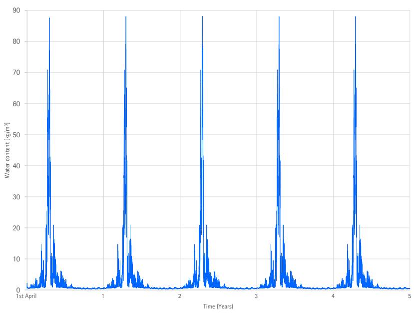
Mould Index of the outer surface of the insulation layer: The Mould Index of the outer surface of the insulation layer is below 1.



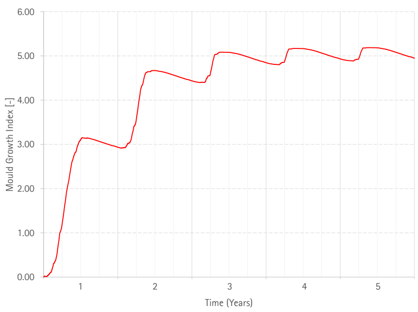
Perth
Construction A: Fibre cement cladding

A1: Construction sealed at WRB only

Condensate in the outer 1 mm insulation layer: The moisture content of the outer 1 mm insulation layer is 88 kg/m³, equivalent to 88 g/m².

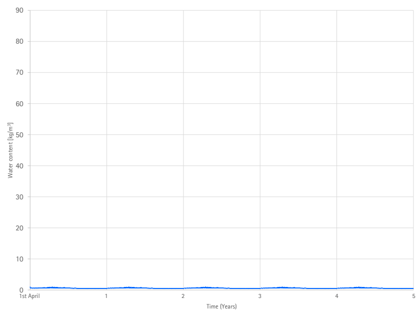


Mould Index of the outer surface of the insulation layer: The Mould Index of the outer surface of the insulation layer is 5.19.

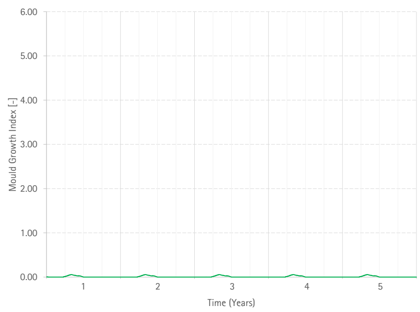


A2: Sealed WRB & INTELLO® PLUS Intelligent Air Barrier System

Condensate in the outer 1 mm insulation layer: The moisture content of the outer 1 mm insulation layer remains very low with the installation of INTELLO® PLUS.



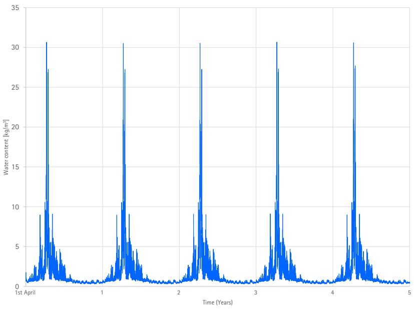
Mould Index of the outer surface of the insulation layer: The Mould Index of the outer surface of the insulation layer is below 1.



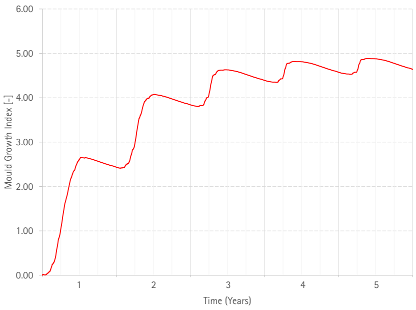
Perth
Construction B: Timber cladding

B1: Construction sealed at WRB only

Condensate in the outer 1 mm insulation layer: The moisture content of the outer 1 mm insulation layer is 31 kg/m³, equivalent to 31 g/m².

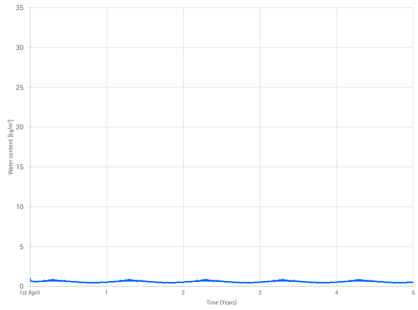


Mould Index of the outer surface of the insulation layer: The Mould Index of the outer surface of the insulation layer is 4.88.

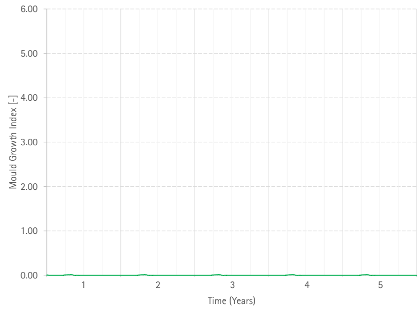


B2: Sealed WRB & INTELLO® PLUS Intelligent Air Barrier System

Condensate in the outer 1 mm insulation layer: The moisture content of the outer 1 mm insulation layer remains very low with the installation of INTELLO® PLUS.



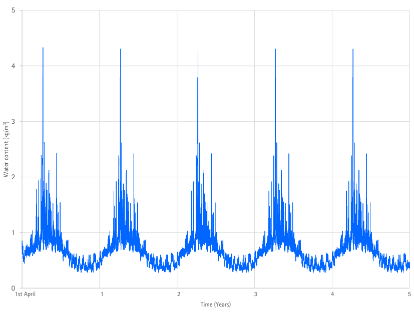
Mould Index of the outer surface of the insulation layer: The Mould Index of the outer surface of the insulation layer is below 1.



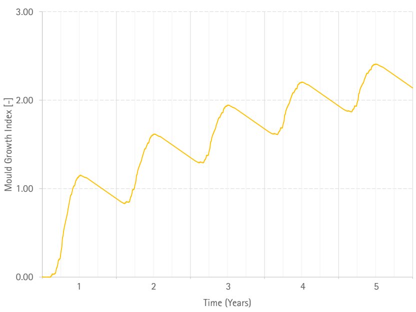
Perth
Construction C: Masonry veneer

C1: Construction sealed at WRB only

Condensate in the outer 1 mm insulation layer: The moisture content of the outer 1 mm insulation layer is 4 kg/m³, equivalent to 4 g/m².

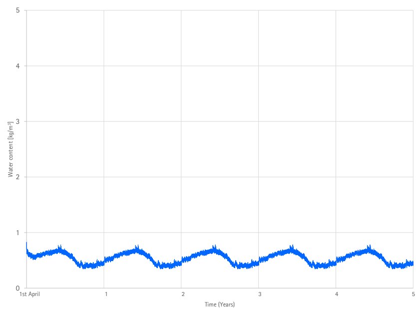


Mould Index of the outer surface of the insulation layer: The Mould Index of the outer surface of the insulation layer is 2.41.

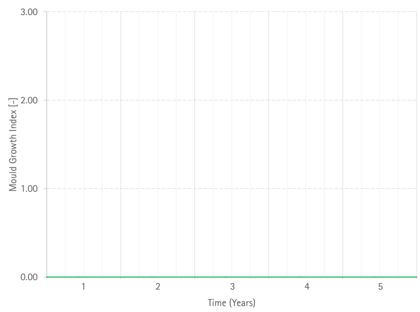


C2: Sealed WRB & INTELLO® PLUS Intelligent Air Barrier System

Condensate in the outer 1 mm insulation layer: The moisture content of the outer 1 mm insulation layer remains very low with the installation of INTELLO® PLUS.



Mould Index of the outer surface of the insulation layer: The Mould Index of the outer surface of the insulation layer is below 1.



6.2.4 Climate zone 4: Mildura

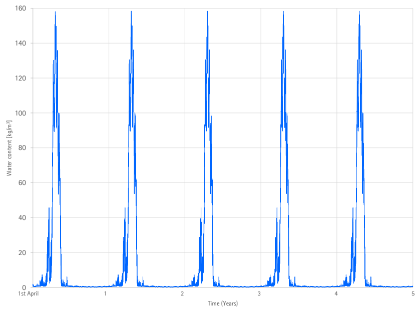
Climate Zone 4 (see chap. 3.2.5) is represented by Mildura climate.
The results of the simulations with exterior-airtightness show moisture content up to 158 kg/m³ and 480 kg/m³ in the outer 1 mm of glass wool insulation. In no scenario is the likelihood of condensate run-off predicted. However, due to the relatively low outside winter temperatures, high humidity is expected for duration where mould growth is likely at the exterior side of the construction systems in all cases.
This assessment is confirmed by a Mould Index of above 5 in the lightweight systems reached within the 3-5 year mark and a moderate mould growth in the brick veneer experienced after 5 years and increasing thereafter. Although hot in summer climate zone 4 still presents a clear risk from mould growth due to the cold winters. All constructions show a risk of endangering the health of the occupants and users of the buildings.

If, on the other hand, INTELLO® PLUS intelligent airtightness system is planned and installed for moisture protection, all the components considered show non-critical moisture content and humidity. No moisture levels that could damage the material or humidity that could endanger health occurs at any point in the building components.

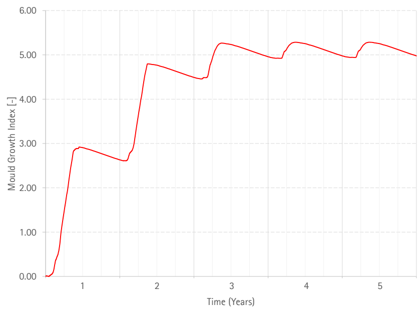
Mildura
Construction A: Fibre cement cladding

A1: Construction sealed at WRB only

Condensate in the outer 1 mm insulation layer: The moisture content of the outer 1 mm insulation layer is 158 kg/m³.

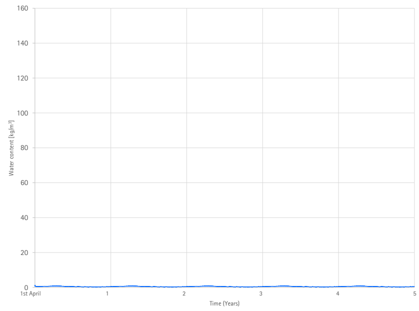


Mould Index of the outer surface of the insulation layer: The Mould Index of the outer surface of the insulation layer is 5.29.

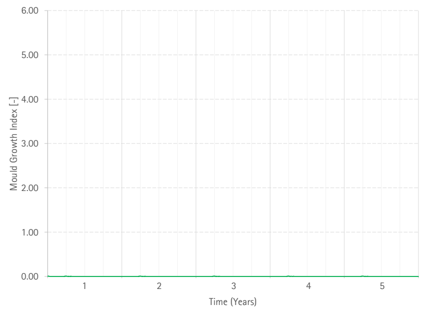


A2: Sealed WRB & INTELLO® PLUS Intelligent Air Barrier System

Condensate in the outer 1 mm insulation layer: The moisture content of the outer 1 mm insulation layer remains very low with the installation of INTELLO® PLUS.



Mould Index of the outer surface of the insulation layer: The Mould Index of the outer surface of the insulation layer is below 1.

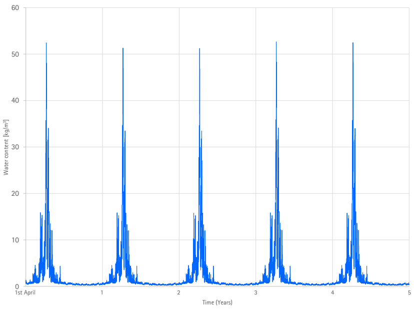


Mildura

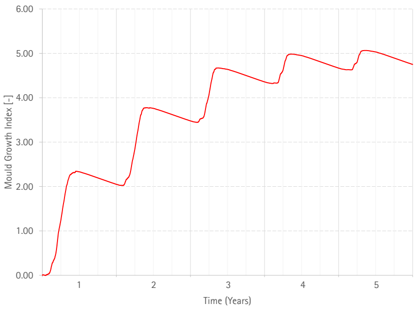
Construction B: Timber cladding

B1: Construction sealed at WRB only

Condensate in the outer 1 mm insulation layer: The moisture content of the outer 1 mm insulation layer is 53 kg/m³, equivalent to 53 g/m².

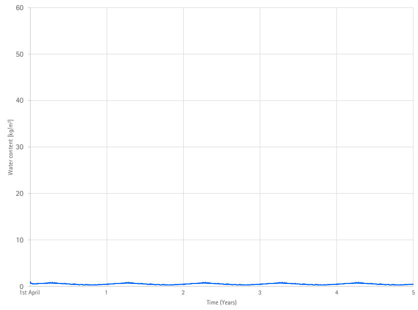


Mould Index of the outer surface of the insulation layer: The Mould Index of the outer surface of the insulation layer is 5.06.

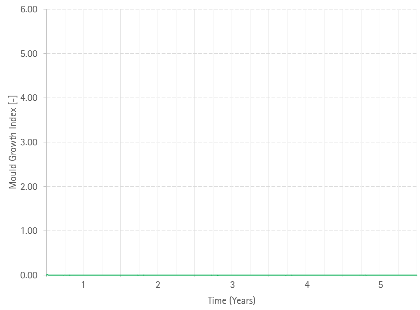


B2: Sealed WRB & INTELLO® PLUS Intelligent Air Barrier System

Condensate in the outer 1 mm insulation layer: The moisture content of the outer 1 mm insulation layer remains very low with the installation of INTELLO® PLUS.



Mould Index of the outer surface of the insulation layer: The Mould Index of the outer surface of the insulation layer is below 1.

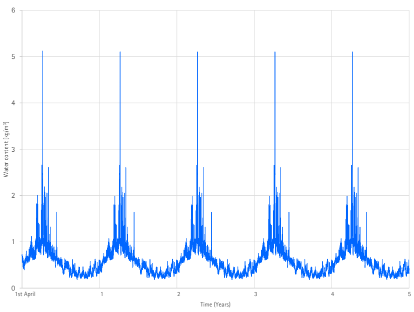


Mildura

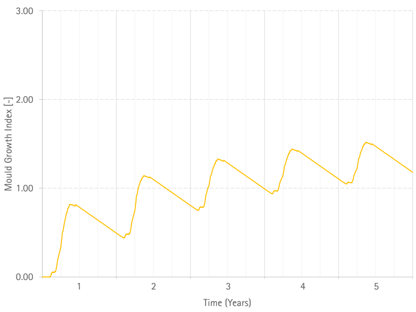
Construction C: Masonry veneer

C1: Construction sealed at WRB only

Condensate in the outer 1 mm insulation layer: The moisture content of the outer 1 mm insulation layer is 5 kg/m³, equivalent to 5 g/m².

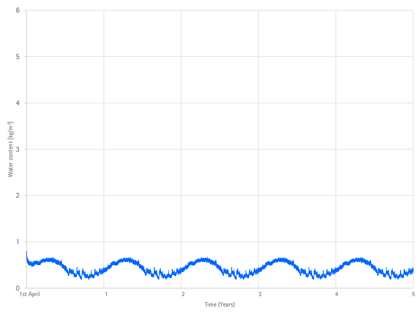


Mould Index of the outer surface of the insulation layer: The Mould Index of the outer surface of the insulation layer is 1.52.

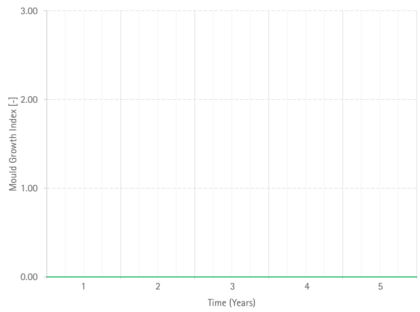


C2: Sealed WRB & INTELLO® PLUS Intelligent Air Barrier System

Condensate in the outer 1 mm insulation layer: The moisture content of the outer 1 mm insulation layer remains very low with the installation of INTELLO® PLUS.



Mould Index of the outer surface of the insulation layer: The Mould Index of the outer surface of the insulation layer is below 1.



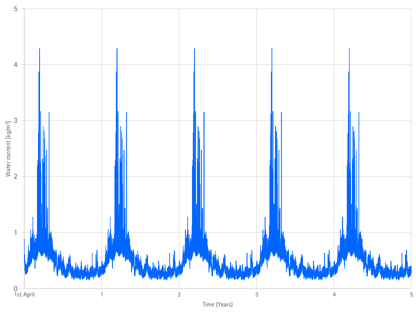
6.2.5 Climate zone 3: Alice Springs

Climate Zone 3 (see chap. 3.2.6) is represented by the location Alice Springs.
The moisture content in the outer 1 mm of mineral fibre insulation, in the absence of airtightness, ranges remains low < 4 kg/m³ during the winter months. These are low and quite tolerable values. When the interaction between moisture and temperature is analysed in terms of possible mould growth it is also evident that the desert like dry climate of Alice Springs does not pose a risk with airtight sealed WRB layers.
This is under the assumption that the external WRB layers are not sealed beyond a 4-5 m³/(m²·h) limit where the scenario may start to show an increased risk to mould growth and health. In this case INTELLO® PLUS is recommended to achieve airtightness levels below 3 m³/(m²·h).

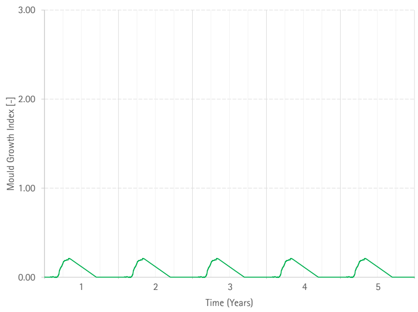
Alice Springs
Construction A: Fibre cement cladding

A1: Construction sealed at WRB only

Condensate in the outer 1 mm insulation layer: The moisture content of the outer 1 mm insulation layer is 4 kg/m³, equivalent to 4 g/m².

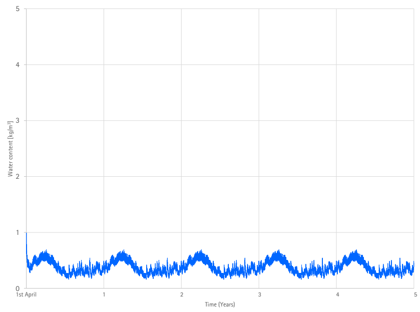


Mould Index of the outer surface of the insulation layer: The Mould Index of the outer surface of the insulation layer is below 1.

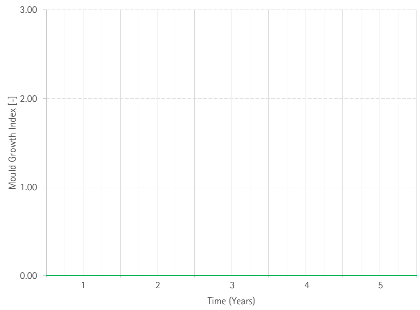


A2: Sealed WRB & INTELLO® PLUS Intelligent Air Barrier System

Condensate in the outer 1 mm insulation layer: The moisture content of the outer 1 mm insulation layer remains very low with the installation of INTELLO® PLUS.



Mould Index of the outer surface of the insulation layer: The Mould Index of the outer surface of the insulation layer is below 1.

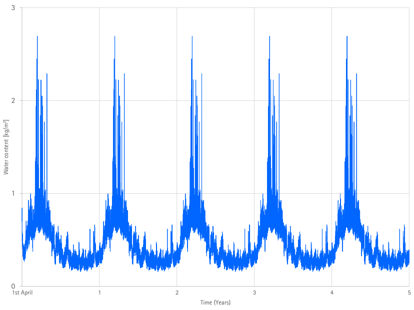


Alice Springs

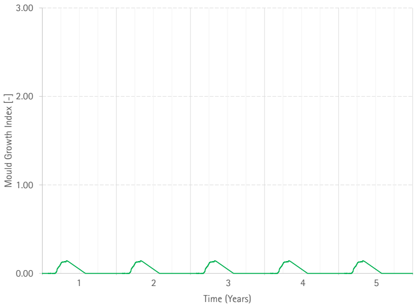
Construction B: Timber cladding

B1: Construction sealed at WRB only

Condensate in the outer 1 mm insulation layer: The moisture content of the outer 1 mm insulation layer is 3 kg/m³, equivalent to 3 g/m².

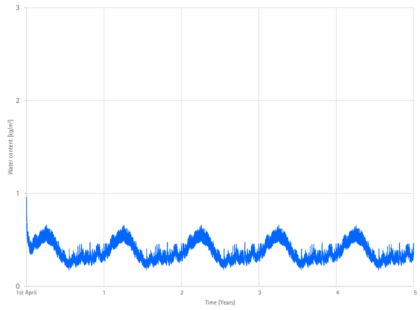


Mould Index of the outer surface of the insulation layer: The Mould Index of the outer surface of the insulation layer is below 1.

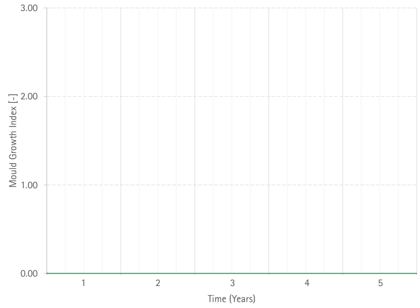


B2: Sealed WRB & INTELLO® PLUS Intelligent Air Barrier System

Condensate in the outer 1 mm insulation layer: The moisture content of the outer 1 mm insulation layer remains very low with the installation of INTELLO® PLUS.



Mould Index of the outer surface of the insulation layer: The Mould Index of the outer surface of the insulation layer is below 1.

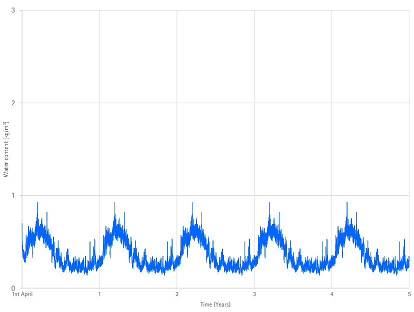


Alice Springs

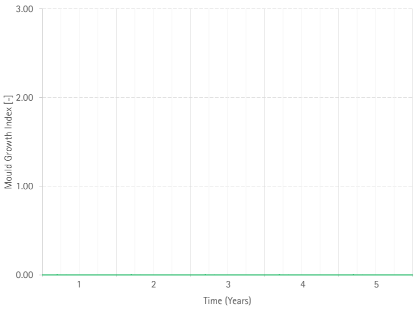
Construction C: Masonry veneer

C1: Construction sealed at WRB only

Condensate in the outer 1 mm insulation layer: The moisture content of the outer 1 mm insulation layer is 1 kg/m³, equivalent to 1 g/m².

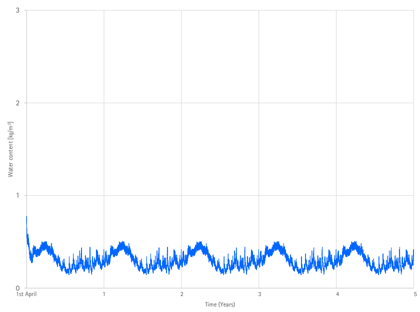


Mould Index of the outer surface of the insulation layer: The Mould Index of the outer surface of the insulation layer is below 1.

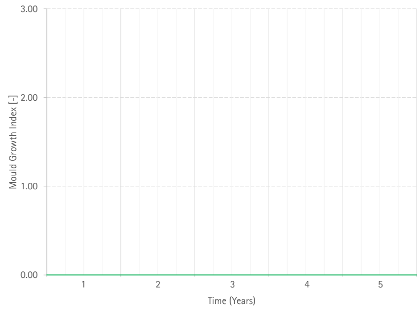


C2: Sealed WRB & INTELLO® PLUS Intelligent Air Barrier System

Condensate in the outer 1 mm insulation layer: INTELLO® PLUS only has a marginal benefit for the moisture content on the outer WRB layer.



Mould Index of the outer surface of the insulation layer: The Mould Index of the outer surface of the insulation layer is below 1.



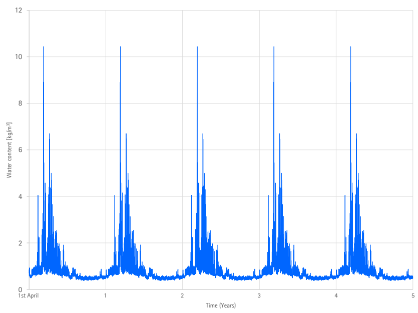
6.2.6 Climate Zone 2: Brisbane

The climate in Brisbane references the Climate Zone 2 (see chap. 3.2.7).
In the designs considered, the maximum moisture content in the outer 1 mm of mineral fibre insulation is of timber and fibre cement facades always below 11 kg/m³ in winter. Compared to other climates considered in the study, this is low, but the warm annual climate pattern provides very good conditions for mould growth. The traffic light is on red.
This becomes clear when looking at the Mould Indexes: For all constructions, the Mould Indexes rise to over 3 for the period under consideration. This means that the components are all in the mould-critical range.
If, on the other hand, airtight construction is used and intelligent moisture management installation, facades with fibre cement panels and wood weatherboards are not critical. The Mould Index is below 1 in each case, so that neither invisible nor visible mould growth occurs. The traffic light colour is green.
Brick veneer construction have an improved hygrothermal balance and reduced risk of mould even without INTELLO® PLUS in a moderately airtight structure (~ 4-5 m³/(m²·h)), the traffic light is green. These building assemblies are not at risk as the thermal inertia in the brickwork means the bricks store some daytime heat and the temperature of the membrane does not drop too low on winter nights. The humidity behind the membrane does not reach critical mould growth levels for any amount of time to be concerned about. In detailing buildings to best practice airtightness the INTELLO® PLUS Intelligent Air Barrier is the most certain way to provide a continuous air barrier system to achieve airtightness levels of < 2 m³/(m²·h).

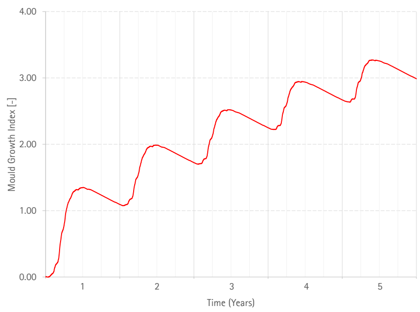
Brisbane
Construction A: Fibre cement cladding

A1: Construction sealed at WRB only

Condensate in the outer 1 mm insulation layer: The moisture content of the outer 1 mm insulation layer is 10 kg/m³, equivalent to 10 g/m².

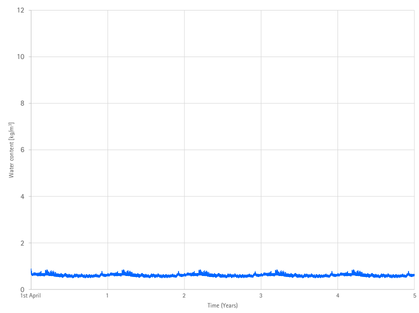


Mould Index of the outer surface of the insulation layer: The Mould Index of the outer surface of the insulation layer is 3.27.

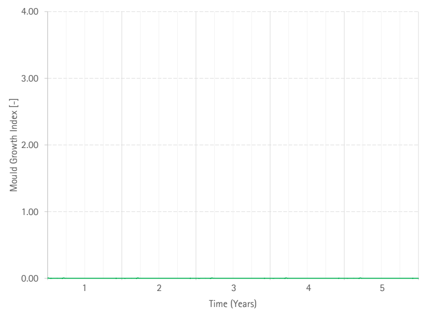


A2: Sealed WRB & INTELLO® PLUS Intelligent Air Barrier System

Condensate in the outer 1 mm insulation layer: The moisture content of the outer 1 mm insulation layer remains very low with the installation of INTELLO® PLUS.



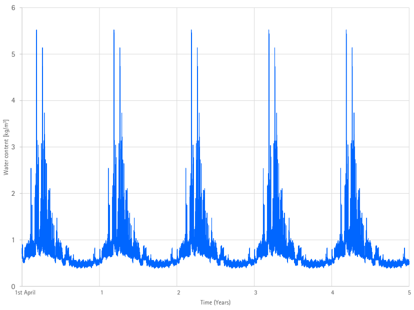
Mould Index of the outer surface of the insulation layer: The Mould Index of the outer surface of the insulation layer is below 1.



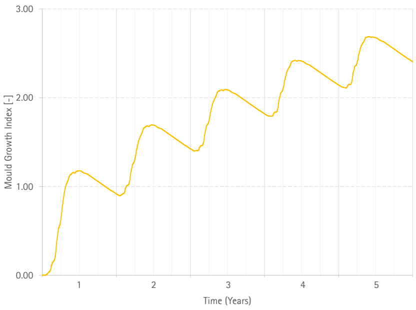
Brisbane
Construction B: Timber cladding

B1: Construction sealed at WRB only

Condensate in the outer 1 mm insulation layer: The moisture content of the outer 1 mm insulation layer is 6 kg/m³, equivalent to 6 g/m².

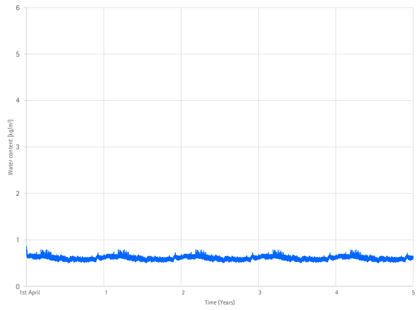


Mould Index of the outer surface of the insulation layer: The Mould Index of the outer surface of the insulation layer is 2.69.

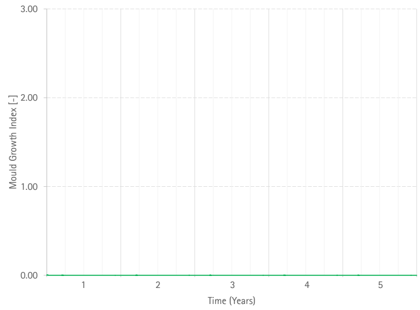


B2: Sealed WRB & INTELLO® PLUS Intelligent Air Barrier System

Condensate in the outer 1 mm insulation layer: The moisture content of the outer 1 mm insulation layer remains very low with the installation of INTELLO® PLUS.



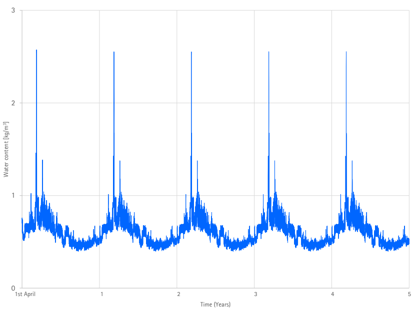
Mould Index of the outer surface of the insulation layer: The Mould Index of the outer surface of the insulation layer is below 1.



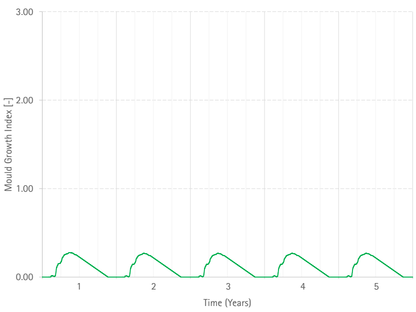
Brisbane
Construction C: Masonry veneer

C1: Construction sealed at WRB only

Condensate in the outer 1 mm insulation layer: The moisture content of the outer 1mm insulation layer is 2.5kg/m³, equivalent to 2.5 g/m².

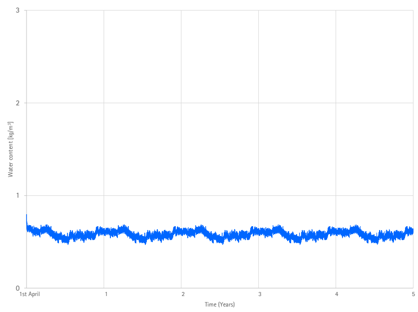


Mould Index of the outer surface of the insulation layer: The Mould Index of the outer surface of the insulation layer is below 1.

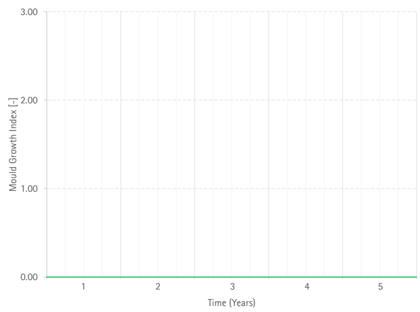


C2: Sealed WRB & INTELLO® PLUS Intelligent Air Barrier System

Condensate in the outer 1 mm insulation layer: The moisture content of the outer 1 mm insulation layer remains very low with the installation of INTELLO® PLUS.



Mould Index of the outer surface of the insulation layer: The Mould Index of the outer surface of the insulation layer is below 1.



6.2.7 Summary for Climate Zone 2 – 8

- Temperatures in Climate Zones 2 – 8 are higher inside than outside in winter. This causes a wintertime diffusion flow of moisture from the inside to the outside. The water vapour diffusing into the construction cools down as it migrates towards the outer layers of the construction. On the outside of the insulation, cool WRB layers can cause the water vapour to condensate.
- Lower outdoor temperatures in the southern climates and thus a greater temperature gradient from the inside to the outside increase the amount of moisture diffusing into the construction. This increases the tendency for high humidity and mould to grow.
- The higher temperatures in the north lead to lower amounts of moisture in the construction, but since mould grows better in warm conditions it also can easily thrive.
- If the constructions are executed without an Intelligent Air Barrier on the inside, higher moisture levels are always created on the outside of the thermal insulation due to diffusion processes. As a result, significant mould growth is to be expected in Climate Zones 4 – 8 (MI above 3 = red) and moderate levels of mould in 2 (MI above 1 = yellow).
- With the Intelligent Air Barrier System pro clima INTELLO® PLUS, installed on the inside of the thermal insulation, the structures always remain dry and mould-free. (MI below 1 = green). To achieve this, the INTELLO® PLUS must be installed in an airtight manner: The overlaps of the membranes are taped airtight (using an adhesive tape with a water-resistant acrylic adhesive), the adjacent building components, are connected airtight with an airtight adhesive (also with water-resistant acrylic adhesive) and penetrations are sealed to the INTELLO® PLUS with sleeves (also with water-resistant acrylic adhesive).
- In Climate Zone 2, brick veneer cladding provides enough thermal capacity to store daytime heat preventing higher humidity behind the membrane at nighttime. This alleviates the risk of mould growth behind SOLITEX EXTASANA® with 0.5 MNs/g (AS / NZS 4200.1-2017 Class 4) vapour resistance.
- Construction systems should be as vapour permeable a possible and only as vapour resistive as necessary. There is no valid reason to increase the vapour resistance more than a class 4 vapour permeable membrane in any climate from 2-8. Keeping higher permeability increases resilience against accidental moisture loads, high indoor occupancy, and rain leaks.
- Weather resistive membranes with active moisture transport through non-porous TEEE functional films (see chapter 4) provide additional security against moisture accumulation in the construction. pro clima SOLITEX EXTASANA®, which is fixed to the studs using staples in accordance with Pro Clima Australia application guide.
- With the intelligent INTELLO® PLUS vapour control membrane, the lightweight structures always exhibit very low moisture levels. The Mould Index is below 1 (green traffic light). The constructions thus have a high potential freedom from structural damage. i.e. they offer a high level of protection against damage even in the event of unplanned moisture (liquid or vapour) intrusion, which may be due to workmanship or planning errors.

6.3 Tropic solutions (cyclonic region)

In Climate Zone 1, the outdoor climate is warmer and more humid than the indoor climate. Consequently, the moisture flow is not directed from the inside to the outside as in Climate Zones 2 – 8, but predominantly from the outside to the inside.
The moisture penetrating from the outside thus increases the moisture content of the internal lining of the building component in air-conditioned buildings. Here, condensation process can lead to the formation of liquid water (condensate). To prevent this, the moisture flow must be reduced by a moderately higher vapour resistance but remaining in the vapour permeable range (AS / NZS 4200.1-2017).
The flexible Weather Resistive Barrier should therefore not be a Class 4 vapour permeable membrane, but more resistive in the upper range of Class 3 or higher, with a vapour resistance of more than 5 MNs/g. Ideally this can be composite vapour resistance of a rigid board with a membrane, preferably a membrane which is adhered on to the board such as SOLITEX EXTASANA ADHERO®.
The exterior Weather Resistive Barrier (WRB) must be absolutely airtight as it is the airtightness and vapour control layer of the construction. It must also be extremely durable under high temperature conditions behind claddings in hot summer sun and resistant to UV exposure prior to cladding over. Membranes which utilise a TEEE film have higher temperature resistance due to the manufacturing process. Laminating of the TEEE and protective fleece layers occurs at high temperature making the temperature resistance of the final product highly suitable for tropical heat. The monolithic structure of the TEEE also makes the products more tolerant to UV exposure prior to cladding with up to 180 days direct UV exposure and still be fit for purpose.
WRB layers should always be clad over as soon as possible in all climates but particularly the tropics. All membranes will have a useable lifetime based on heat and minor exposure to UV through cladding and flashing gaps. Maximum UV exposure tolerance ensures the membranes use up less of their serviceability life in the initial construction phase. Membranes with greatest UV exposure are always preferable for weatherproofing longevity.
Lightweight steel constructions are not the most common wall construction in Climate Zone 1. Still built, steel structures are often

preferred due to the reduced termite risk.
In this climatic zone, buildings are sometimes exposed to violent storms and cyclones, which stress the buildings and the facades due to a high mechanical load on them due to the wind pressure and additional risk due to extremely heavy rain. Therefore, WRB membranes in climate zone 1 are always beneficial to be installed on a rigid board. Full-surface adhesive membranes, such as pro clima SOLITEX ADHERO®, are advantageous here, as no fasteners such as staples and nails exist. This has advantages during the construction phase when there are strong winds & rain before the cladding is fixed. It has also advantages in the case that a storm damages the facade. The SOLITEX ADHERO® is not a separate layer like a membrane but part of the board and therefore resistant to wind flapping and rain exposure in an emergency.
In these cyclonic regions buildings in Climate Zone 1 are usually constructed using masonry construction methods. These are either rendered or can possibly be clad with fibre cement cladding or fibre cement weather boards with a drained cavity behind. If weather protection is required for a ventilated masonry construction, the SOLITEX ADHERO® with a drained and ventilated cavity is advantageous for optimum rain management. The waterproof TEEE functional film protects the masonry from the weather during the construction phase and after completion of the structure, even when exposed to cyclonic winds.
The fully adhesive nature means that any localised damaged to the product or installation imperfections on the surface will mean that water leaks are isolated in this extreme climate.

6.3.1 Boundary conditions and details for Climate Zone 1

WUFI® Pro was used for hygrothermal simulation of the moisture flows and temperature curves of a lightweight wall construction with a fibre cement cladding, to determine the moisture content in the critical layers of the component, and to evaluate any mould infestation that might occur.
Worst-case scenarios were used as the basis. This approach is therefore useful and crucial in order to take into account unfavourable conditions that may regularly occur in subareas of the building component constructions.
These include, for example, building geometry (including corners, setbacks and overhangs) as well as built-in components (windows and doors) or penetrations (pipes, conduits or cables) where water ingress is more likely. Depending on planning and execution, so-called "unforeseen residual leakage risks" of outdoor humid air or rain can occur into the completed building envelope, so it makes sense for design safety to take further reserves into account when evaluating the results.
The principle is generally known, but often forgotten: if the safety reserves (drying) are sufficiently high, no structural damage will occur even in the event of unscheduled moisture loads. For this purpose, the amount of possible drying should be higher than the acting moisture loads.
The simulations were based on the following general conditions:

- Orientation of the wall component to the north: Sunlight hits the component directly here and generates a high level of heating.
- Medium colour of the facade (absorption coefficient a=0.5): 50 % of the incident sunlight is reflected, 50 % is converted into thermal energy.
- Higher ventilation rate in the back ventilation rate of the outer wall cladding (ventilation rate: 30 1/h): this is based on worst case ventilation that introduces a lot of (warm and humid) air into the ventilated cavity.
- On the inside, a paint on the gypsum boards with a diffusion resistance of 3.5 MNs/g.

The diffusion resistance on the inside determines how much of the moisture arriving from the outside will accumulate on the inside, even with the risk of condensation and thus liquid water in the structure. Waterproof surfaces, such as latex paints and tiles used in kitchens and in bathrooms are calculated with a diffusion resistance of 10 MNs/g according to the recommendations of the Fraunhofer Institute for Building Physics. [70]

6.3.2 Construction details of the wall

The calculation starts at the beginning of the winter half-year on April 1. The calculation period is five years.
From outside to inside:

- Wall cladding: Construction: Fibre cement cladding, 10 mm
- Drainage cavity, ventilation rate: 30 air changes per hour
- Weather Resistive Barrier:
  - Version 1: With a very air leaky weather resistive barrier, representing typical installation of "sarking" materials with non-sealed overlap joints allowing free flow of water vapour, equivalent to a vapour resistance of zero.
  - Version 2: SOLITEX EXTASANA® as a flexible WRB membrane, taped and sealed at all joints (non-porous TEEE membrane) » moisture vapour diffusion resistance: 0.5 MNs/g
  - Version 3: SOLITEX EXTASANA ADHERO® (non-porous TEEE membrane) fully adhered to a rigid plywood sheet bracing (sheathing) » vapour resistance: 5 MNs/g (rigid sheathing + WRB SOLITEX EXTASANA ADHERO®)
- Glass wool, 90 mm
- Plasterboard, 10 mm
- Paint: moisture vapour diffusion resistance: 3.5 MNs/g

6.3.3 Environmental conditions and location

Outdoor climate: For the simulations, the city of Darwin was selected as representative for Climate Zone 1. The further details correspond to those in chapter 6.1.3.

6.3.4 Layers critical to building physics with the risk of condensation

In contrast to the previously described Climate Zones, in climate zone 1 it is necessary to reduce the moisture input due to diffusion and convection coming from the outside. High moisture transport by convection or diffusion from the outside can lead to a critical moisture load on the cool air-conditioned inside of the component, which means an increased risk of mould growth due to the increased surface humidity adjacent the cool plasterboard.

The penetrating moisture cools down in the structure, leading to an increase in relative humidity and thus to a high moisture load. The moisture load coming from the outside is slowed down from drying out to the inside by the internal building components which may have higher diffusion resistances. Interestingly it is common in tropical climates to specify semi-gloss paints for their superior ability to be wiped clean. A diffusion resistance of 3.5 MNs/g (e.g. Semi Gloss) is assumed for interior paint finish as the value used in this study – interior tiles have a diffusion resistance of 10 MNs/g and are thus even less favourable.

Inward moisture flow can be reduced to acceptable levels by a higher resistance weather resistive barrier on the outside (more than 5 MNs/g which is the upper range of class 3: vapour permeable, AS/NZS 4200.1-2017).

The moisture content of the inner 1 mm of the mineral fibre insulation and the Mould Index are analysed as the primary point of risk in Climate Zone 1.

6.3.5 Layers critical to building physics with the risk of mould

The risk of mould growth is investigated using the VTT model and the Mould Index (MI) which is outlined in the AIRAH DA07 manual - see Table 5.6, Chapter 5.2.3.

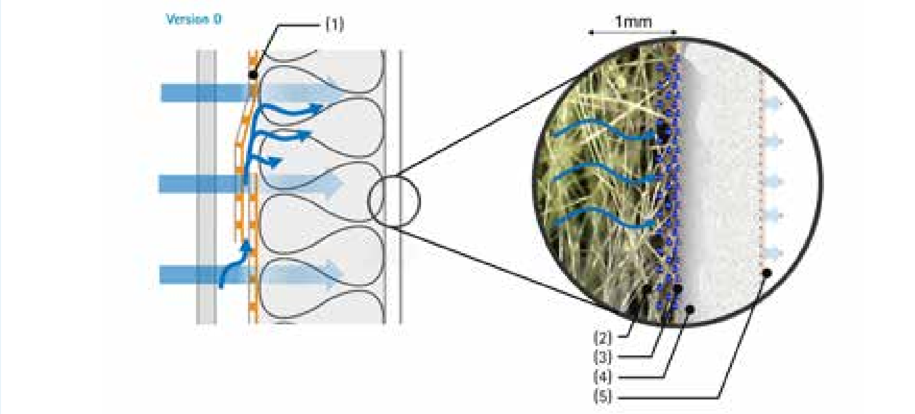


Figure 6.9: Wall Construction D – Poorly sealed WRB provides poor diffusion control. Excessive air leakage will result in air transported water vapour reaching the cool plasterboard surface creating high humidity where mould can proliferate. (1) Poorly sealed WRB provides limited diffusion control & poor water proofing; (2) Humid conditions in the 1 mm glasswool layer; (3) Gypsum paper facing (food for mould); (4) Mould growth risk on paper face and within gypsum; (5) Semi-gloss paint finish (3.5 MNs/g) resists drying

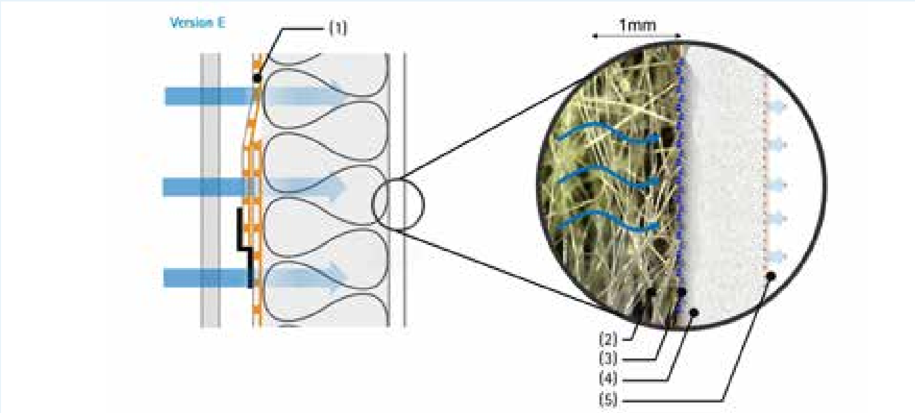


Figure 6.10: Wall Construction E – Sealed class 4 vapour permeable membrane. Too much vapour permeability on the membrane can also result in excessive inward diffusion. High humidity can result on the back side of the gypsum board where mould can proliferate. (1) Sealed WRB provides diffusion control depending on the vapour permeability; (2) Humid conditions in the 1 mm glass-wool layer; (3) Gypsum paper facing (food for mould); (4) Mould growth risk on paper face and within gypsum; (5) Semi-gloss paint finish (3.5 MNs/g) resists drying

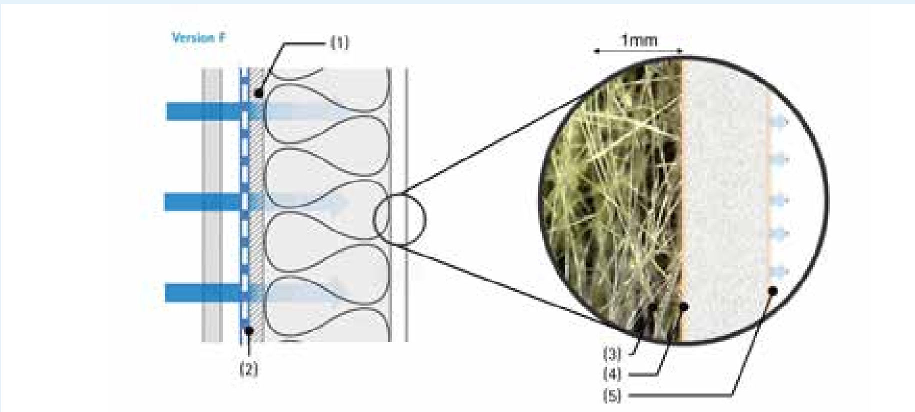


Figure 6.11: Wall Construction F – Very well sealed WRB utilising a peel and stick membrane over a rigid substrate provides optimal diffusion control. Superior wind tightness ensures no air transported water vapour. Class 3 vapour classification of SOLITEX EXTASANA ADHERO® provides perfect outcome. The gypsum board remains dry and free from mould. (1) Rigid bracing board with peel & stick membrane; (2) Wind tight composite WRB system used for diffusion control limiting water vapour into assembly; (3) Dry conditions in the 1 mm glaaswool layer; (4) Gypsum paper facing (Dry); (5) Semi-gloss paint finish (3.5 MNs/g)

6.3.6 Evaluation

According to the calculations with WUFI® Pro, the construction with a weather resistive membrane lacking windtight/airtight connections leads to a moisture load of 1.2 kg/m³ water in the 1 mm thick mineral fibre insulation. Although this is not considered a high water content at all the associated MI quickly reaches 3.5 because of the consistent high humidity at the paper facing of the plasterboard. It the consistent high humidity that drives risk of mould albeit without any risk of liquid water run-off as the indoor air conditioning temperature is never extremely low (sub-zero) like outdoor temperatures in cold climates.

With a Weather Resistive Barrier (TEEE membrane) that is open to diffusion (moisture vapour diffusion resistance: 0.50 MNs/g » class 4: vapour permeable) and designed to be airtight, there is still a high moisture load of 1.0 kg/m³ although it takes longer to grow. This leads to a calculated Mould Index of 3.1, which is above the healthy threshold. With SOLITEX EXTASANA ADHERO® in combination with a sufficiently load-bearing board material (rigid sheathing, 3 MNs/g), only 0.7 kg/m³ of water precipitate is present in the inner 1 mm thermal insulation layer. It's not that the moisture content is substantially lower but the fact that the high humidity conditions remain below critical mould growth thresholds due to the wind/airtight peel and stick membrane and the additional resistance of the adhesive and board that allow enough throttle on the inward diffusion to keep mould on the internal lining at bay - the MI is also close to 0. In the wet tropics, waterproofing is essential and that SOLITEX EXTASANA ADHERO® offers very high security in case of damage due to its full-surface bonding to the rigid substrate materials. With no membrane fixings (staples or fasteners) required risk is greatly reduced as a result of strong driving rain.

The risk of mould in concrete block or SOLID masonry is far less due to the hygric buffering effect of the masonry. This is one of the major construction types in this region. In these structures mould is most likely caused by liquid water leaks under rain load in these high rainfall regions. Waterproofing in the wet tropics is of utmost importance.

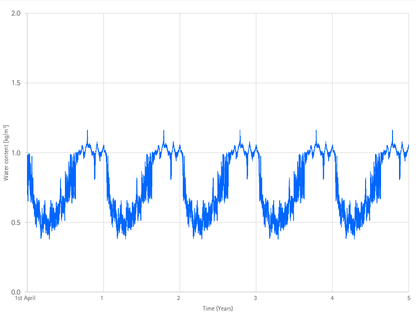
SOLITEX EXTASANA ADHERO® can be applied over SOLID concrete or concrete block work for optimal weather protection, then overclad with a lightweight cladding ensuring the cladding and the SOLITEX EXTASANA ADHERO® are separated by a drained and ventilated cavity for optimal outcomes. Fibrous insulation can then be added to the inside of the structure for optimal outcomes in all respects of hygrothermics.

Darwin

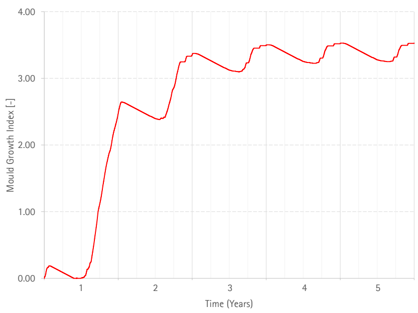
Construction: Fibre cement cladding

Construction D: Not airtight (0.00 MNs/g)

Condensate in the inner 1 mm insulation layer: The moisture content of the inner 1 mm insulation layer is 1.2 kg/m³, equivalent to 1,2 g/m².

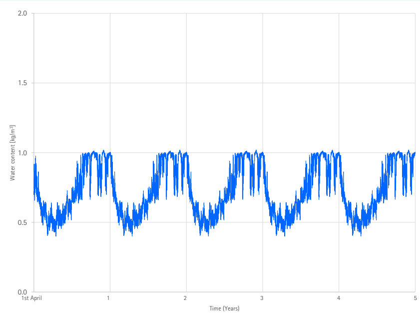


Mould Index of the inner surface of the insulation layer: The Mould Index at the back side of the interior plasterboard lining is over 3 after just 2 years.

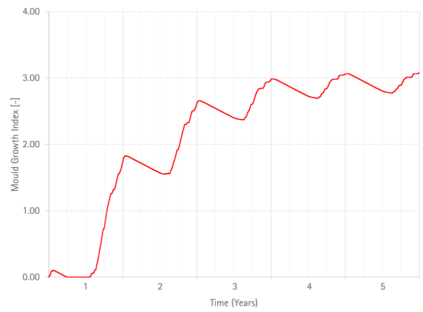


Construction E: Airtightness with SOLITEX EXTASANA® (0.50 MNs/g)

Condensate in the inner 1 mm insulation layer: The moisture content of the inner 1 mm insulation layer is 1.0 kg/m³, equivalent to 1,0 g/m²



Mould Index of the inner surface of the insulation layer: The Mould Index at the back side of the interior plasterboard lining is over 3 after 4 years.

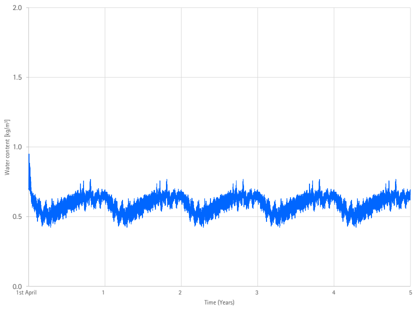


Darwin

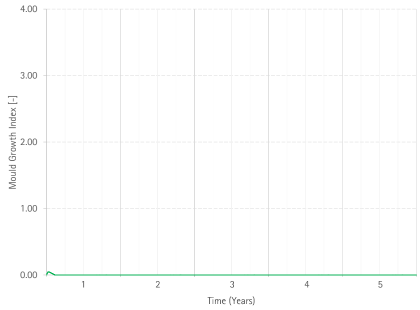
Construction: Fibre cement cladding

Construction F: Airtightness with SOLITEX EXTASANA ADHERO® over a rigid plywood board (5 MNs/g)

Condensate in the inner 1 mm insulation layer: The moisture content of the outer 1 mm insulation layer is low by the installation of the WRB SOLITEX EXTASANA ADHERO®



Mould Index of the inner surface of the insulation layer: The Mould Index at the back side of the interior plasterboard lining remains free from mould.



6.3.7 Summary for Climate Zone 1

- Buildings in climate zone 1 are challenged by the high vapour diffusion flows from the outside climate. The penetrating moisture laden air cools down in the construction as it nears the internal air.
- Conditioned linings and thereby leads to a high moisture load on the inside of the plasterboard linings.
- In air-conditioned buildings in the tropics it is imperative that the external WRB layers are as airtight as possible. This means sealing to international best practice to limit air transported water vapour.
- The weather resistive membranes must be airtight. The membranes must be taped at the overlaps, connected to the adjacent building components and sealed at the penetrations. This is also required to achieve adequate water proofing.
- Since the temperature of the outside climate in Climate Zone 1 is generally higher than the temperature inside the building, the opposite rule applies compared to cold climates. The WRB must be designed as an airtight layer & it must be located on the outside of the fibrous thermal insulation in the stud frame.
- A class 4 WRB (below 0.88 MNs/g) can lead to moisture build up behind the interior plasterboard lining, due to high moisture transport from the outside into the structure. A moderately increased diffusion resistance of the WRB then protects the construction better against diffusion from the outside.
- The thermal insulation structure should be protected on the outside in climate zone 1 by a layer with a diffusion resistance of above 5 MNs/g. This will protect the component from moisture. This protects the component from humidification and mould. At the same time, significant drying to the outside is enabled.
- The principles for walls apply in the same way to ceilings and roofs of buildings.
- Tropical climates experience high solar gains and high UV intensity. This means WRB layers with both high UV resistance and high temperate resistance are necessary.
- Monolithic TEEE manufacturing technology allows membranes to achieve 180 days UV exposure and continuous operating temperatures exceeding 100 °C and remain fit for purpose, windtight and water barrier properties. This technology used in SOLITEX ADHERO® for ultimate safety in tropical climates.
- In combination with waterresistant adhesive tapes TESCON EXTORA® and TESCON EXTOSEAL® adhesion is unaffected my moisture (vapour or liquid), weatherproof constructions with the highest safety level are possible through adequate vapour diffusion control achieving optimum healthy buildings.
- Optimal for the high mechanical stresses due to wind and moisture loads due to humidity in Climate Zone 1 the ideal weather resistive barrier WRB is SOLITEX EXTASANA ADHERO®, which is bonded over the entire surface of any rigid board or masonry substrate.
- The cyclone region has high wind loads. It is recommended to apply the WRB on a suitable (termite resistant), load bearing board material (plywood, oriented strand board, fibre cement or exterior grade gypsum).

Figure 6.12: Lamination of materials with differing co-efficient of expansion/contraction under heat stress results in deterioration and ultimate delamination of the material layers. [71]

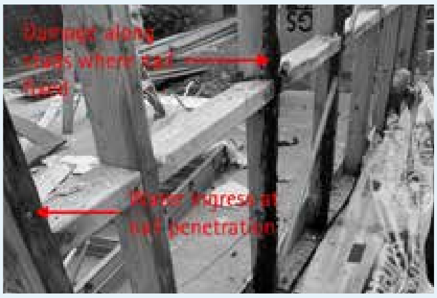


Figure 6.13: High resistance membranes provide little drying capacity and "safety buffer" for when things don't go according to plan. A site in Marrickville, Sydney, with direct fix cladding allowed water pentration through the nail fixings leading to water ingress and very limited drying potential leading to structural damage. [72]

6.4 Aluminium foil

Aluminium foil is produced largely for the food packing industry. The foil itself is intended to inhibit vapour from entering into the food packaging and causing early expiration of the perishable food within. Any building wraps with foil layers also have a very high diffusion resistance and do not allow moisture to pass through. They are used on the outside (often cold side) under the pretext that they will reflect radiant heat both outwards and/or inwards adding thermal R-value to the construction system. However, reflection of radiant heat (infra red wavelengths) only occurs from low emittance foil surfaces when there is a cavity adjacent the infra red surface. The effect of any reflection of radiative heat is negated when any other SOLID materials, including bulk fibre insulation is pushed up against the foil surface. Likewise, the degree of reflection depends on the surface quality which is effected by dust, contamination, mould and oxidation. Durability of the aluminium surface is also of concern if it delaminates from the woven polymer substrate to which it is bonded. Polymers tend to shrink under heat and foil layers tend to expand with heat. These are two fundamentally different and opposing coefficients of expansion leading to damaging effects as seen in image 6.12.

When aluminium foils are applied to the outside of a construction, it can no longer release water vapour to the outside and dry out. Water vapour diffusion is the mechanism by which water vapour exits the insulated stud bays and allows structures to dry. The moisture flow from the inside to the outside is completely blocked by the barrier and regardless of the inclusion of any ventilated cavities or not on the exterior of the vapour barrier, drying cannot & will not occur. The higher the temperature difference between the inside and outside climate, the more critical this becomes. In a colder climate, the greater the temperature difference and thus the water vapour pressure differential & driving force pushes strongly to the outside. This then leads to very cold non-porous surfaces and relative humidity reaches 100 % for prolonged periods of time. This means large amounts of condensate precipitate behind the aluminium foil. This often presents problems when water drains creating soggy bottom plates, noggings and absorption of moisture into the external side of the timber frame studs. See image 6.13.

The same effect can be observed with aluminium foil on the inside. Here, the foil blocks water vapour diffusing inwards in the reverse direction in summer and consequently leads to moisture accumulation on the inside. Further to this safety hazards are of concern when aluminium foils are in close proximity to electrical wiring and must be labelled accordingly "electrically conductive".

Vapour barriers were restricted in use decades ago by NZ regulators on the base of decades of international research and by sensible guidance from BRANZ. Using decades of scientific backing BRANZ was able to guide NZ on the right track and make the rational decision to guide regulators to ban these products from the NZ market.

In Australia, due to emerging issues and international learnings from NZ and further abroad aluminium foils were banned on the outside of insulation layers in Climate Zones 6, 7, and 8 in the 2019 building code. For climate zones 2, 3, 4 and 5, the risks are still being debated amongst industry organisations, but scientific consensus has been established that aluminium foils on the outside of fibrous insulation systems is poor practice from Climate Zone 2-8.

As a rule, INTELLO® PLUS is beneficial for all building physics challenges, i.e. INTELLO® PLUS equips constructions with a high potential freedom from building damage. It always leads to lower moisture in the outer cold layers of the construction and thus offers a high level of protection against mould. However, it is not a miracle cure for stupidity, aluminium foil vapour barriers on the outside of the stud insulation are a vapour trap which can at best be mitigated with INTELLO® PLUS but by no means completely solved.

In the following, the moisture behaviour is calculated using WUFI® Pro. A typical wall construction with fibre cement cladding is shown for some Climate Zones:

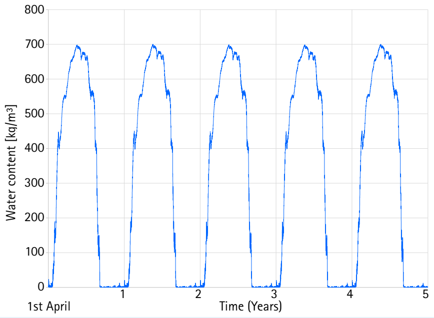
- 7 Canberra (prohibited)
- 5 Sydney (permitted but under vigorous debate at time of publication of this study)
- 4 Mildura (permitted but under vigorous debate at time of publication of this study)
- 2 Brisbane (permitted but under vigorous debate at time of publication of this study)

Evaluation, wall A - fibre cement cladding, Mould Index on the outside of the glass wool. South orientation, comparison: aluminium foil with and without INTELLO® PLUS.

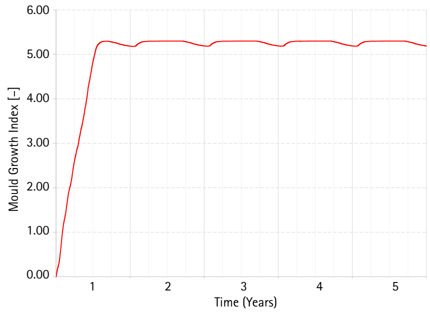
Canberra

Construction sealed with foil

Condensate in the outer 1 mm insulation layer: The moisture content of the outer 1 mm insulation layer is 700 kg/m³, equivalent to 700 g/m² and will certainly result in liquid condensate run-off.

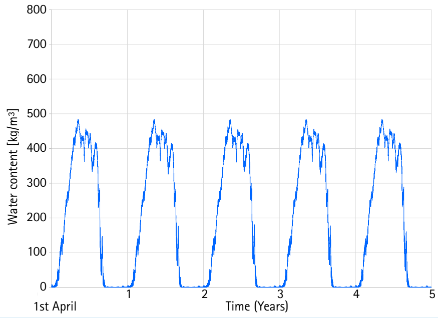


Mould Index of the outer surface of the insulation layer: The Mould Index of the outer surface of the insulation layer is 5.3 leading to a high chance of mould infestation.

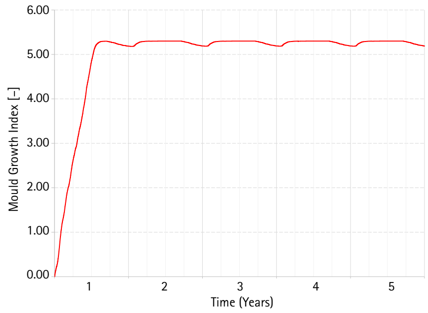


Sealed Foil with INTELLO® PLUS Intelligent Airtightness System

Condensate in the outer 1 mm insulation layer: The moisture content of the outer 1 mm insulation layer is 484 kg/m³, equivalent to 484 g/m². This will almost certainly result in liquid condensate run-off.



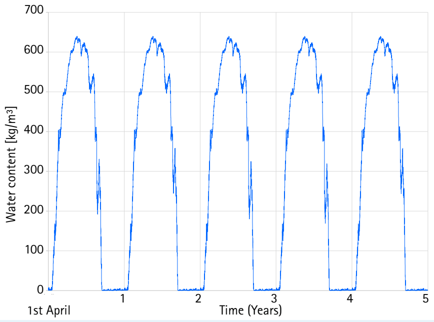
Mould Index of the outer surface of the insulation layer: The Mould Index of the outer surface of the insulation layer is 5.3 leading to a high chance of mould infestation.



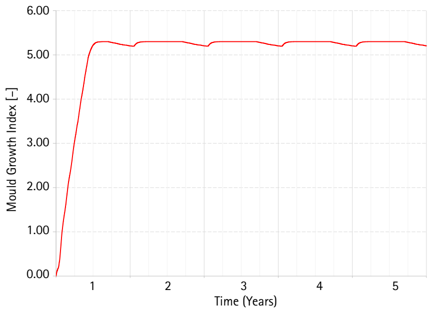
Melbourne

Construction sealed with foil

Condensate in the outer 1 mm insulation layer: The moisture content of the outer 1 mm insulation layer is 640 kg/m³, equivalent to 640 g/m² and will certainly result in liquid condensate run-off.

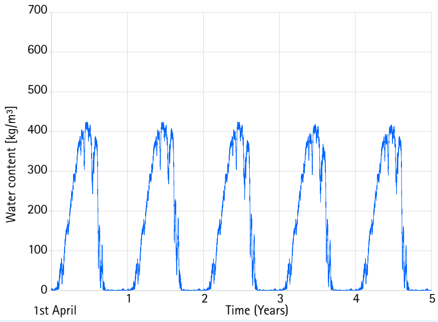


Mould Index of the outer surface of the insulation layer: The Mould Index of the outer surface of the insulation layer is 5.3 leading to a high chance of mould infestation.

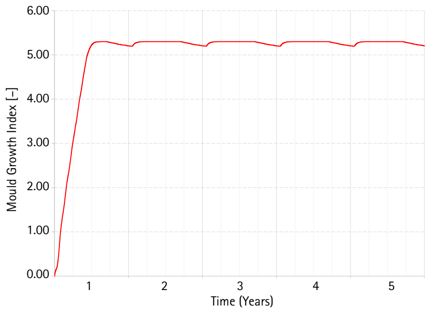


Sealed Foil with INTELLO® PLUS Intelligent Airtightness System

Condensate in the outer 1 mm insulation layer: The moisture content of the outer 1 mm insulation layer is 424 kg/m³, equivalent to 424 g/m² which will almost certainly result in condensate run-off.



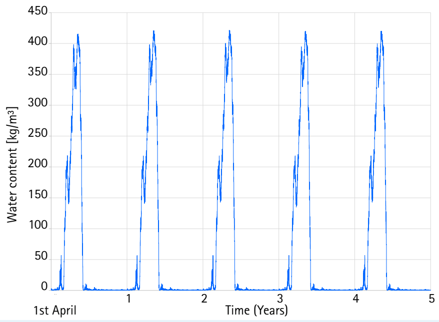
Mould Index of the outer surface of the insulation layer: The Mould Index of the outer surface of the insulation layer is 5.3 leading to a high chance of mould infestation.



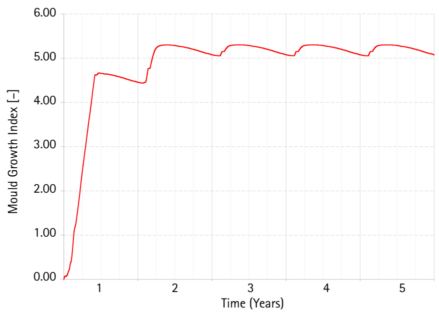
Sydney

Construction sealed with foil

Condensate in the outer 1 mm insulation layer: The moisture content of the outer 1 mm insulation layer is 421 kg/m^3, equivalent to 421 g/m^2 which will almost certainly result in condensate run-off.

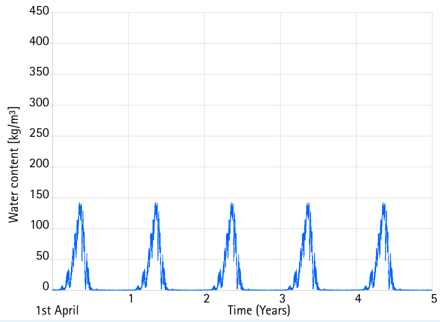


Mould Index of the outer surface of the insulation layer: The Mould Index of the outer surface of the insulation layer is 5.3 leading to a high chance of mould infestation.

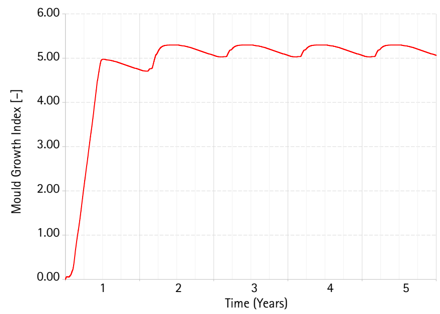


Sealed Foil with INTELLO® PLUS Intelligent Airtightness System

Condensate in the outer 1 mm insulation layer: The moisture content of the outer 1 mm insulation layer is 142 kg/m^3, equivalent to 142 g/m^2 which is reduced below the critical moisture level and run-off prevented.



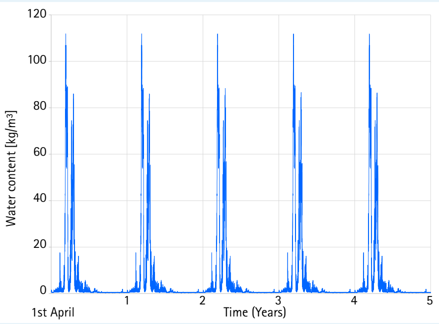
Mould Index of the outer surface of the insulation layer: The Mould Index of the outer surface of the insulation layer is 5.3 leading to a high chance of mould infestation.



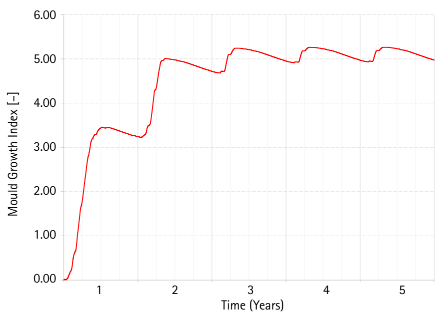
Brisbane

Construction sealed with foil

Condensate in the outer 1 mm insulation layer: The moisture content of the outer 1 mm insulation layer is 112 kg/m^3, equivalent to 112 g/m^2, no liquid water run-off is expected.

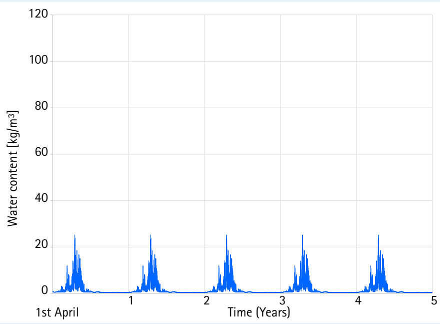


Mould Index of the outer surface of the insulation layer: The Mould Index of the outer surface of the insulation layer is 5.3 leading to a high chance of mould infestation.

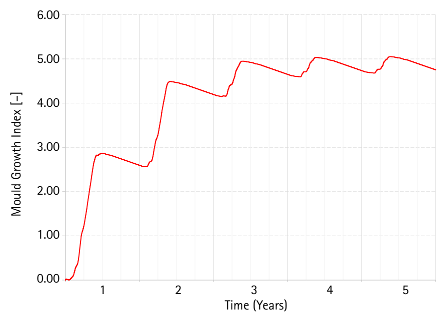


Sealed Foil with INTELLO® PLUS Intelligent Airtightness System

Condensate in the outer 1 mm insulation layer: The moisture content of the outer 1 mm insulation layer is 25 kg/m^3, equivalent to 25 g/m^2, no liquid water run-off is expected.



Mould Index of the outer surface of the insulation layer: The Mould Index of the outer surface of the insulation layer is 5.3 after just 3 years leading to a high chance of mould infestation.



Excessive condensate is likely in all climates which leads to large amounts of liquid which can easily produce run-off in cooler climates including Sydney and anywhere further south. Even with 329 kg/m² maximum condensate which can be held within the 1 mm layer of glass wool adjacent the aluminium foil vapour barrier, without a vapour control layer on the inside of the insulation this threshold is exceeded in Sydney, Melbourne and Canberra. This means that it is expected that condensate can run-down the back of the aluminium into the bottom plate.

6.4.2 Summary

- A weathertight aluminium foil membrane on the outside of an insulated framed structure is likely to induce mould growth in Canberra, Melbourne, Sydney and Brisbane very quickly. Condensate will form in all cases for a duration of time that will ultimately result in visible mould within just 1-2 years.
- An internal vapour control layer will greatly reduce the amount of condensate running down the back of the foil in Sydney and Brisbane, but cannot prevent run-off in Melbourne or Canberra.
- Despite the positive effect of an internal intelligent vapour control layer on mitigating run-off it cannot be expected to eliminate high humidity behind the WRB and the potential for mould growth behind the aluminium foil.
- It is expected that wintertime conditions in all climates 2-8 quickly elevate the humidity behind the membrane creating perfect conditions for mould growth.
- The use of INTELLO® PLUS is not considered a solution to prevent detrimental outcomes when using strong vapour barrier WRB to weatherproof on the outside of the structure.

6.5 Summary

- Constructions without internal air sealed Air Barriers with intelligent vapour control have a significant risk in terms of induced mould behind the WRBs in all climates.
- The building code requires the risks associated with water vapour and condensation to be managed to minimise their impact on the health of occupants.
- Liquid run-off to the extent that water drains down is possible in climate zone 6, 7 & 8.
- The possibility of unhealthy conditions due to mould and/or decay is probable in most climates with well implemented wind tight weather barriers, even if they are class 4 vapour permeable.
- In Climate Zones 2-8 an intelligent air barrier system on the inside of the thermal insulation eliminates all risk of excessive condensation and health risks when used with a class 4 permeable WRB.
- In Climate Zone 1 the WRB should be air sealed on the outside of the thermal insulation. It acts as the air barrier and needs to be sealed to achieve best practice standards.
- In Climate Zone 1, a rigid board with the full adhesive SOLITEX EXTASANA ADHERO® membrane provides a well-sealed exterior WRB. This provides optimum rainwater and water vapour management in tropical cyclonic climates.
- The higher the safety reserves are (the higher the construction damage-free potential), the more safety margins that are designed in for unplanned moisture sources that can arise, for example, due to weather-related events (wind & rain), workmanship issues (air gaps), detailed planning errors (trade cross-over issues), or non-perfect drainage design.
- Therefore, constructions are recommended where the calculations show an MI index of less than 1, i.e. have a sufficient safety buffer to prevent long term mould.
- INTELLO® PLUS on the inside (in climate zone 2-8) provides sufficient protection of water vapour entering into the construction while allowing for maximum drying potential in summer due to the vapour variable "intelligent" response of the membrane.

Figure 7.1: Attic space with wet foil sarking in contact with perimeter ceiling insulation [73]

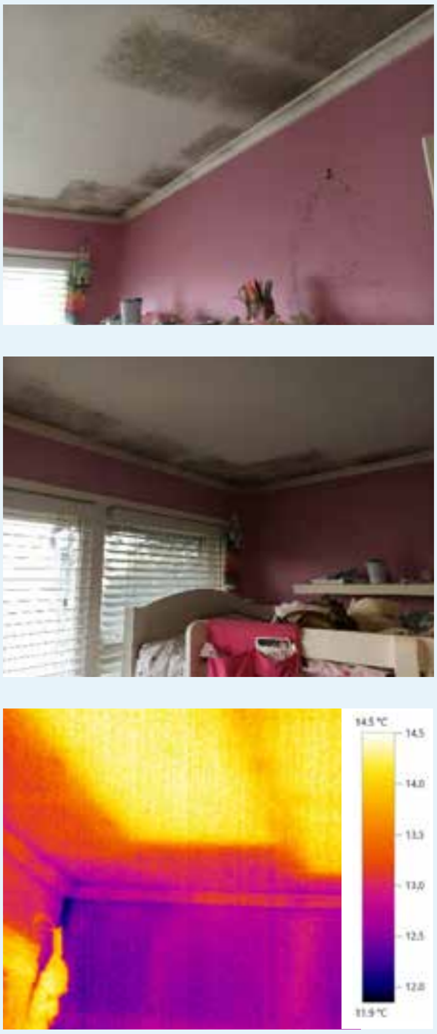


Figure 7.2: Perimeter mould in children's bedroom. [74]

7. Roofing

7.1 Hygrothermally unbalanced

In Australia we are increasing our energy efficiency. As we do this, we create new problems. As we do this we create new problems where the walls in the roofing systems become unbalanced from a heat and moisture perspective. The effect is we haven't been constructing roofs the best way possible.

7.1.1 Trusses – Love them or hate them

When dealing with moisture problems it is necessary to have continuous insulation. Although this is specified in the building code it is rarely actually achieved, especially in trussed roofing. Ceiling perimeter mould is often caused by either condensation from roof vapour barriers wicking into insulation (Figure 7.1), or missing ceiling insulation around the perimeter of trusses. Missing insulation results in cold internal plaster temperatures and causes high surface humidity at cornices creating mould (Figure 7.2).

Continuous insulation is necessary to manage internal surfaces temperatures on the plasterboard ceiling. Australian Standard AS 3999 Installation of Bulk Insulation [75] suggests the insulation can be thinned out around the edges where the pitching point crosses the top plate of the wall.

This may have as little as 70 mm of clearance and therefore could only have a maximum of 40 mm (R1.0) to ensure the insulation safely clears the roof cladding or roofing membranes without wicking condensate into the ceiling insulation. (Figure 7.3)

A reconfiguration of the roof trusses is necessary as an interim step to properly achieve continuous ceiling insulation (Figure 7.4). Even if the trusses are reconfigured such that the entire roof sits 200 – 300 mm higher to accommodate the insulation, there is a major issue with upward vapour diffusion through the permeable plasterboard and insulation layers and even worse direct movement of moisture laden air across the plaster ceiling contributing moisture to the roof space. Continuous insulation must be combined with a continuous undamaged INTELLO® PLUS Intelligent Air Barrier (IAB) with vapour variable control to ensure moisture protection of the roof space. This is further discussed in section 7.3.9.

In the case of Figure 7.4 the additional eave height needs to be accounted for in window shading design. Egress and maintenance are often a big issue, the truss design can account for this to ensure insulation is not compressed when routine maintenance is undertaken. Figure 7.5 indicates a truss web design to increase access.

Ideally a truss roof can best be achieved using an insulated cassette first laid onto the walls as in Figure 7.6. This allows for continuous insulation and a robust attic space that is fully trafficable and easily maintained. The service cavity is critical to allow for lighting cables in which all is done from below and not routed through the roof space. The roof can then be ventilated as required for optimal summer performance without degradation to winter performance and reduced R-value due to wind washing.

7.1.2 Cathedral & skillion roofs

Cathedral and skillion style roofs in Australia commonly contain insulation at the plasterboard line as well as a layer compressed hard up against the cladding (Metal roofs). Ventilation is then forced between the insulation layers introducing outdoor air through the centre of the insulated assembly. This is arguably good for summer performance, but you have essentially eroded the value of the insulation in winter. The key benefit of the cathedral and skillion style roof is that the systems can eliminate large air voids (attic spaces) which can redistribute humid air in unpredictable ways. Precise ventilation cavities designed directly to the underside of the cladding (metal or tile) is superior. This is known as Above Membrane (Sheathing) Ventilation and allows for optimum winter (moisture management) and summer (heat removal) performance. Further discussed in section 7.2.

If attics in pitched roofs are used as additional living space the physical demands on them are like those for walls. (Figure 7.7 & 7.8) It is beneficial to have a construction that is diffusion open on the outside with a ventilated cavity behind the cladding. The construction make up is very similar to a drained and ventilated wall assembly as shown in figure 7.9.

Under the roof cladding, thermally insulated roof constructions need a diffusion-open and properly functioning WRB, to meet Australia's varying climatic demands. The ideal solution is a combination of intelligent moisture management on the inside and diffusion-open roof underlay of the SOLITEX MENTO® products on the out-

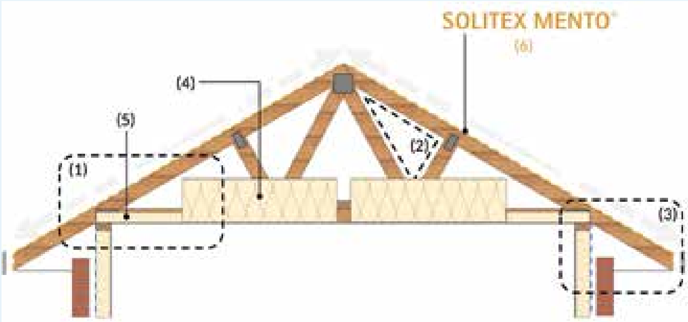


Figure 7.3: Traditional Truss roof with a modification to insulation layer attempting to prevent moisture wicking into the insulation and cornice as per AS 3999. (1) Perimeter insulation issues, (2) Difficult egress pathway in roof space, (3) Eaves hang lower relative to window head height providing good overall shading for windows, (4) Bulk insulation, (5) Perimeter insulation, (6) SOLITEX MENTO® & ventilated cladding assembly

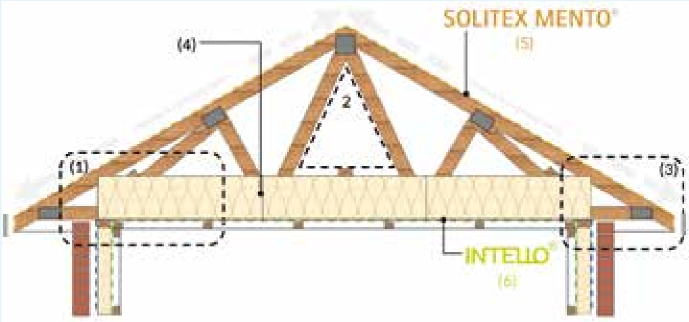


Figure 7.4: Modified truss with increased height to accommodate full insulation width and inclusion of an Intelligent Air Barrier to manage upward movement of internal water vapour. (1) No perimeter insulation compression issues, (2) Roof space egress down centre, (3) Eaves are higher relative to window head and design adaptation will be required for adequate shading, (4) Bulk insulation, (5) SOLITEX MENTO® & ventilated cladding assembly (6) Internal Intelligent Air Barrier pro clima INTELLO®

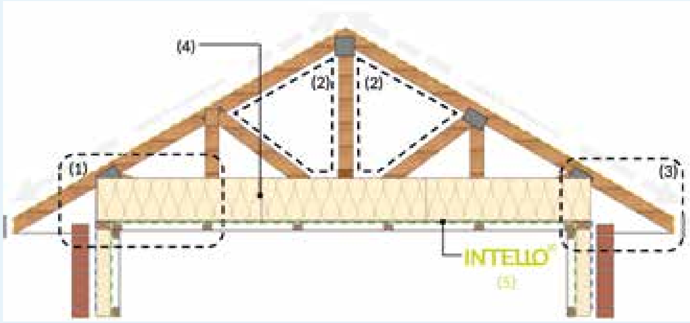


Figure 7.5: Modified truss web to increase the ease of egress into the roof space for maintenance issues. (1) No perimeter insulation compression issues, (2) Difficult egress pathway in roof space, (3) Eaves are higher relative to window head and design adaptation will be required for adequate shading, (4) Bulk insulation, (5) SOLITEX MENTO® & ventilated cladding assembly, (6) Internal Intelligent Air Barrier pro clima INTELLO®

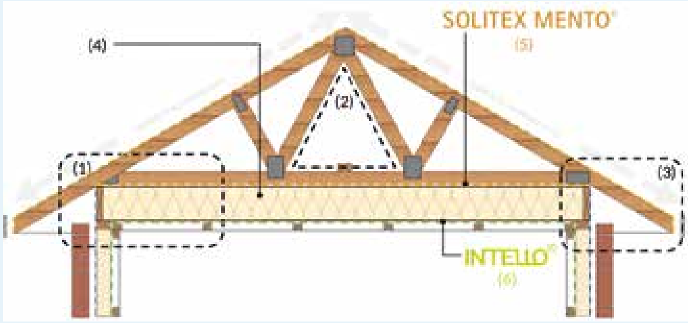


Figure 7.6: Truss applied on a fully enclosed cassette. Including internal Intelligent Air Barrier and external wind tight layer for optimal moisture and energy performance. (1) Continuous insulation cassette, (2) Roof space egress down centre with trafficable attic floor, (3) Eaves are higher relative to window head and design adaptation will be required for adequate shading, (4) Bulk insulation, (5) SOLITEX MENTO® wind tightness layer, (6) Internal Intelligent Air Barrier pro clima INTELLO®

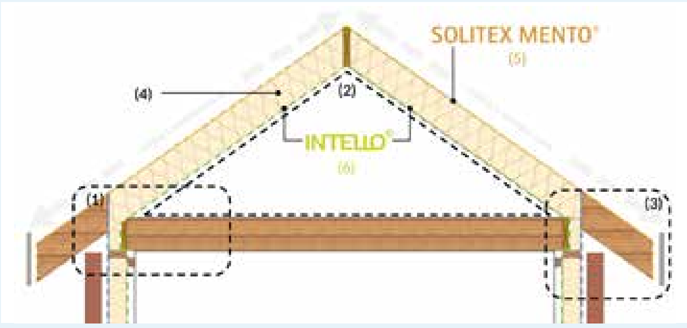


Figure 7.7: Ideal cathedral roof structure has the same components as a wall system; vapour permeable weather restive barrier, Intelligent Air Barrier on the inside and a ventilated cavity behind the cladding. (1) Continuous insulation, (2) Usable roof space – habitable and/or storage, (3) Steeper roof slope allows for better shading, (4) Bulk insulation, (5) SOLITEX MENTO® & ventilated cladding assembly, (6) pro clima INTELLO®

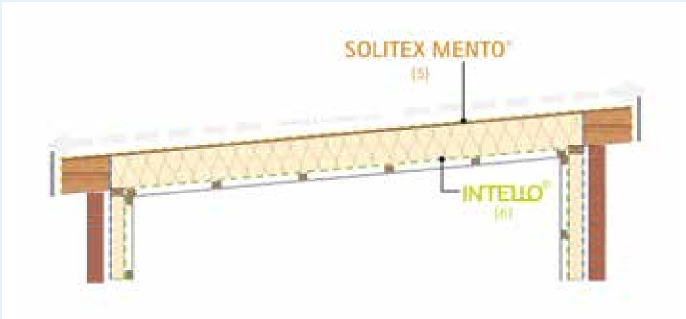


Figure 7.8: Ideal skillion roof structure has the same components as a wall system; vapour permeable weather restive barrier, Intelligent Air Barrier on the inside and a ventilated cavity behind the cladding. (5) SOLITEX MENTO® & ventilated cladding assembly, (6) pro clima INTELLO®

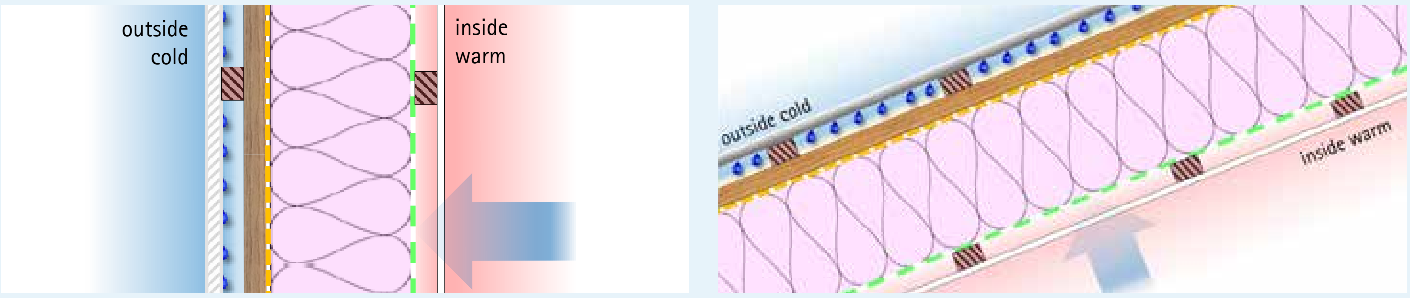


Figure 7.9: A drained and ventilated wall cavity is used to remove water, condensate and evaporate moisture. In summer, the ventilated cavity removes heat by convection. This wall assembly on its side forms the ideal roof configuration. A drained and ventilated roof assembly works in the same way.

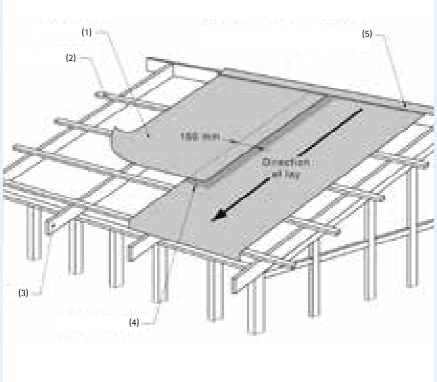


Figure 7.10: This roof is typical of the way we have been doing roofs in Australia – with a membrane over purlins and the roofing material installed directly on to the membrane. This arrangement presents some problems. [77] (1) Membrane, (2) Purlin/batten, (3) Rafter, (4) 150 mm overlap, (5) Continuous over ridge or 150 mm overlapp on each side

Figure 7.11: This is not a leaky roof. The amount of condensation forming on the underside of roofing metal is more than what can be absorbed or drained by the underlay and puddles form. The extreme conditions under the metal have also caused wrinkles & sagging, plus mould is starting to grow. [78]

Figure 7.12: Temperature fluctuations cause expansion and contraction of underlay materials which can lead to rips and tears, especially in composite membranes where different materials behave differently with varying temperatures. [78]

side. This provides maximum protection for the building envelope and contributes to a healthy living environment: pro clima INTELLO® PLUS ensures no uncontrolled moisture movement from the inside by diffusion or convection, and pro clima SOLITEX MENTO® PLUS on the outside; a non-porous, diffusion-open, and thermally stable membrane with high UV tolerance. SOLITEX® membranes transport the moisture actively along the molecular chains as well as high mechanical strength, which makes installation on the building site easier and provides a high level of protection to the system once the building is in use.

7.2 Cladding treatment

At the cladding level correct design and implementation is critical. The cladding surface gets extremely cold in winter and extremely hot in summer. Your roofs need to work in all cases. This makes Australian climates particularly difficult in many respects.

Roofs are there to keep us dry. This seems fairly simple when we just want to shed water away and do not have to worry about things like condensation. But as well as being protected from the rain, we would also quite like to be warm, and we would like for it to not consume too much energy to keep us warm. To help with this, we have added insulation and sealed up parts of our building envelopes. Now we are dealing with temperature gradients and vapour pressure, and things are getting interesting. Most of us are all too familiar with what happens when it is relatively warm and humid inside and cold outside. If our building envelopes are not designed and constructed to deal with these differences in indoor and outdoor conditions, we end up with condensation.

Condensation is one symptom of poor building envelope design. New Zealand deals with this symptom by requiring an absorptive material to be placed directly under the roofing iron (like AS 4200.2 shown in Figure 7.10. [76] The theory is that any condensation that forms (usually at nighttime) will either be absorbed by this roofing underlay or drained away. Then when the roofing material heats up (during the day), the heat will essentially bake the underlay dry again. Problems start to occur when this cycle is repeated day in, day out. The underlay material is exposed to some extraordinary conditions. Super high temperatures occur in the middle of summer and very cold temperatures (often five to ten degrees below ambient air temperature) are common during winter nights. Just how high is high? Research shows that 90 °C is not uncommon. [79] [80] [81]. In dark-coloured roofs in hot Australian climates such as Townsville, solair temperatures were both calculated and field-measured to exceed 90 °C. [82]

Add continual wetting and drying to these extreme temperature fluctuations and the conditions created become similar to what laboratories use for accelerated aging! What sort of materials can withstand this sort of treatment? Unsurprisingly, not many. Most membranes and tapes will look very worse-for-wear after only a few short years of their intended life under these conditions (see Figure 7.11 & 7.12).

As well as the stresses and resulting damage to membranes, there are other problems with putting roofing material directly on top of an underlay over battens or rafters:

- Penetrations through the roof cladding create holes in the underlay, thereby creating lots of little pathways for any condensation to leak through into the rest of the building.
- When moisture accumulates in excess of what can be absorbed, the system relies on free drainage. Free drainage relies on a clear path all the way down to the eave and ideally into the roof guttering. But extreme temperature and humidity changes typically cause expansion and contraction of the materials which leads to sagging, and this in turn can create ponding (see Figure 7.11). The problem is particularly apparent in low pitched roofs and where there is no SOLID substrate (sheathing) supporting the underlay.
- Wrinkles, folds, and multiple areas of direct contact severely limit any effective ventilation of what limited gap there is between the roof and underlay. In addition, most roofers go to great lengths to seal up this space as much as possible by folding down corrugation ends and installing tight fitting flashings.
- Extreme temperatures impact the health, comfort and efficiency of the building. As noted above, temperatures under the roof cladding of a typical construction where there is not adequate ventilation can reach up to 90 °C. This heat can transfer into the building either contributing to discomfort or unnecessarily adding to the energy required to keep cool.

- In truss roofs, the top of the insulation is left unprotected. There is just a big space between the underlay and the insulation. In this setup, air is free to move around and through the top layer of the insulation, thereby reducing its effectiveness in winter.

There is a better way to design and build our roofs and it is all about putting adequate ventilation in the right place, because:

- Ventilation below roof cladding is better than absorption for managing moisture.
- Ventilation between the roof cladding and the membrane is better than cladding reflectance.

With all this in mind, international research has led to a solution known as "Above Sheathing Ventilation".

7.2.1 Let's be flexible

Strictly speaking in this part of the world, it's 'Above Membrane Ventilation'. Sheathing is the SOLID substrate installed on top of structural elements and underneath the cladding (see Figure 7.13). It's a term commonly used in the US for the rigid boards that are laid over the rafters of roof trusses. This board has a structural function but is also there for holding up the water barrier membrane and supporting it against wind loads behind the cladding systems.

If we were describing a wall, then a rigid air barrier would be an example of sheathing. And as with walls, where not all situations require a rigid air barrier, a flexible barrier without sheathing may be sufficient. This flexible barrier might be a membrane, or sarking.

Therefore, we could call this method, "Above Sarking Ventilation" but in Australia "sarking" typically means foil. Foils are discouraged because non-permeable membranes (even perforated ones) don't have a place in modern buildings as has been discussed in chapter 4.

So, while "Above Sheathing Ventilation" (ASV) may not always be a completely accurate descriptor, at least Australia will have some consistency with the rest of the world. Let us not get too hung up about the word "sheathing" though. The most important word in ASV is Ventilation.

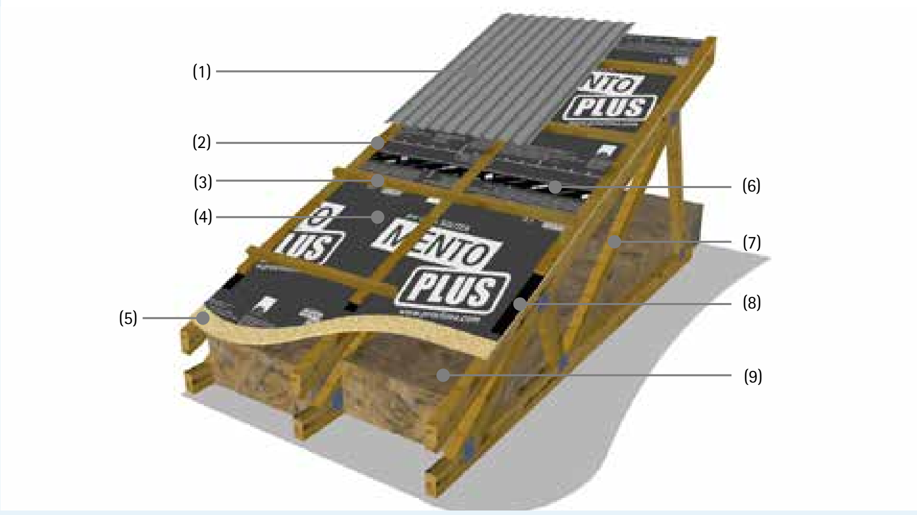


Figure 7.13: Technically, "sheathing" refers to rigid boards placed onto the rafters or top chord of a truss to support the membrane under the cladding while providing structural support to the roof. (1) Roof sheeting (medium colour), (2) Counter batten, (3) Fixing batten, (4) SOLITEX MENTO®, (5) Sheathing (bracing), (6) TESCON EXTORA® (Weathertight sealing tape), (7) Roof truss, (8) TESCON® NAIDECK (Double sided self-sealing strip), (9) Fibrous insulation

Figure 7.14. Tear in metal sheet roofing from hail damage allowing for water penetration [83]

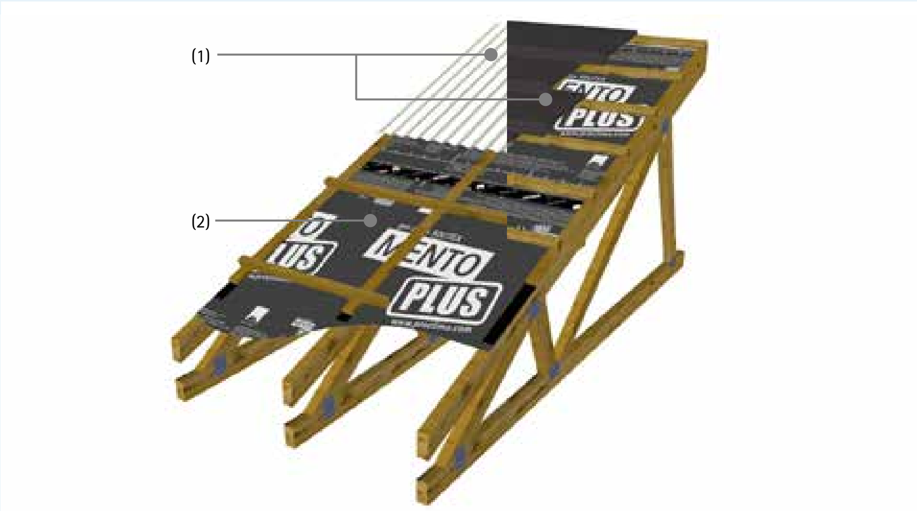


Figure 7.15: Roofing systems should always contain a first line of defence for deflection and drainage and a second line of defence; to ensure storm resilience. The second line of defence should be in the form of a Weather Resistive Barrier (WRB). Below 10° the WRB should be supported by rigid sheathing to avoid the risk of ponding. (1) Primary deflection layer (1st line of defence), (2) WRB (2nd line of defence)

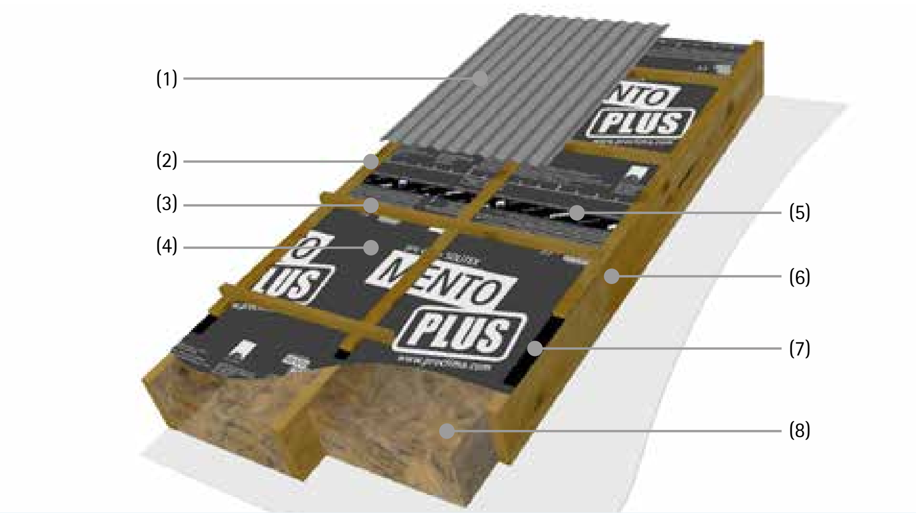


Figure 7.16: In a skillion roof, the ventilated cavity should be created between the underside of the roof cladding and the roof membrane. The membrane is placed directly on top of, and in contact with the insulation. It's separated from the roof cladding by battens and counter battens. *Specific products may vary. (1) Roof sheeting (medium colour), (2) Counter batten, (3) Fixing batten, (4) SOLITEX MENTO®, (5) TESCON EXTORA® (Weathertight sealing tape), (6) Roof rafter, (7) TESCON® NAIDECK (Double sided self-sealing strip), (8) Fibrous insulation

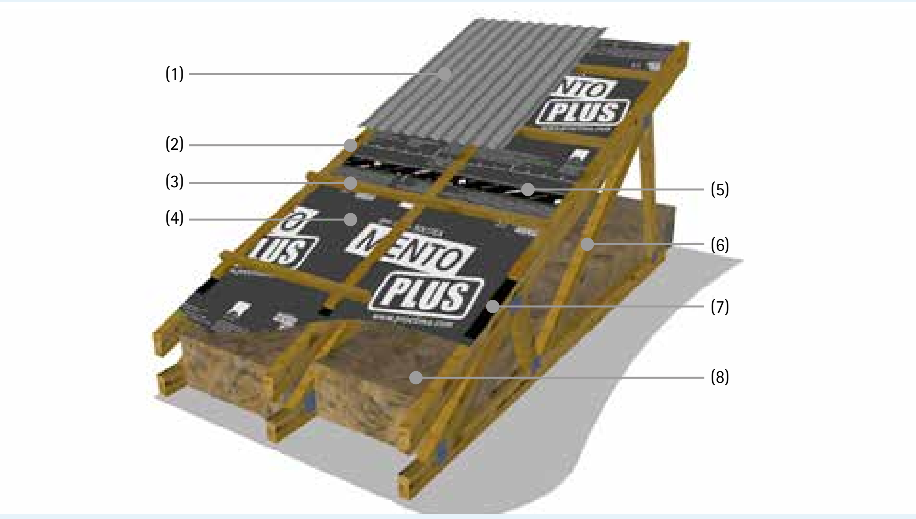


Figure 7.17: The ventilation arrangement for a typical truss roof is the same as for a skillion roof. A ventilated cavity is created between the roof cladding and the membrane by battens and counter battens. The insulation is still protected by the membrane above, but with a void between them. *Specific products may vary. (1) Roof sheeting (medium colour), (2) Counter batten, (3) Fixing batten, (4) SOLITEX MENTO®, (5) TESCON EXTORA® (Weathertight sealing tape), (6) Roof truss, (7) TESCON® NAIDECK (Double sided self-sealing strip), (8) Fibrous insulation

Figure 7.18: Ready for the roofing cladding to be installed, this site shows the arrangement of counter battens (running vertically) and battens (running horizontally) to form a drained and ventilated cavity. *Specific products may vary. [84]

7.2.2 A ventilated cavity

A result of the $47 billion [85] "leaky building" crisis is that most New Zealanders are familiar with the concept of, and importance of, a ventilated cavity with respect to walls. Why should roofs be any different?
While most would agree that ventilation in the roof is a good idea, there is some confusion about the best place for it.
A common assumption is that ventilation already occurs, either under the peaks of metal corrugations, or in the small (and irregular) spaces between the edge of tiles and any underlying membrane. These air spaces are relatively small and should not be confused with the air layer in "ventilated" roof assemblies. The intent should be to have specifically designed ventilation in a specific location for a specific purpose.

7.2.3 Where the membrane goes

In Australia, pitched roofs with clay or concrete tiles have typically been constructed with a membrane directly beneath the tiles and a ventilation layer underneath this membrane. It is also common to have no secondary weatherproofing layer below the roof tiles at all. The theory is that if (or when) the cladding leaks, then large quantities of airflow in the roof will dry out the construction.
It is generally acknowledged that broken tiles are possible either by extreme weather or from foot traffic during maintenance procedures. However, when it comes to long run metal roofs, the continuous metal sheeting is often believed to be a perfect water barrier, so "she'll be right mate!". (see Figure 7.14 & 7.15)
However, membranes play an important role in the building envelope. They're the real weatherproofing layer because we know that claddings aren't perfect. All building cladding will eventually leak. The weathertightness membrane should be placed where it provides the best protection for the thermal layer of the building envelope. In a wall or skillion roof, this means directly in contact with the insulation (see Figure 7.16).

7.2.4 Wind and rain

The combination of wind and rain at any given time is known as driving rain (see also chapter 2.7).
It is generally accepted that gravity forces water downwards. Except when it does not.

Water being driven against the flow of gravity by wind should not be underestimated. Wind driven rain must be accounted for in any roof design, whether it be continuous long run metal or tile.
A good cladding system is the first line of defence. Beneath this, a secondary line of defence is required, and this should take the form of a WRB. Truss roofs are more common in Australia. In this instance, the same attention should be paid to designing the ventilation space between the roof cladding and the membrane. It is essentially the same as for a skillion and a sealed membrane layer creates a chimney (see Figure 7.16 & 7.17).

7.2.5 Above Sheathing Ventilation (ASV)

ASV can be implemented by adding counter battens (running vertically) directly above the weather-tightness membrane. Regular battens (running horizontally) are then attached above the counter battens to form the fixing structure for the roof cladding (Figure 7.18). The counter batten construction provides an air space between the exterior face of the roof sheathing and the underside of the roof cladding so that a clear air pathway exists beneath the roof cladding from the soffit to the ridge.

7.2.6 Solar powered ventilation

ASV uses energy from the sun to induce an airflow in the air space between the cladding and the membrane. The sun heats up the roof cladding and this heat is transferred to the air in the cavity below. The warmer, and therefore more buoyant air moves up the inclined air gap creating solar powered ventilation (see Figure 7.19).
Miller, Wilson, and Karagiozis (2006) observed that this type of ventilation helped remove unwanted heat and moisture from the roof deck, thereby improving the roof's thermal performance as well as its durability. [86]

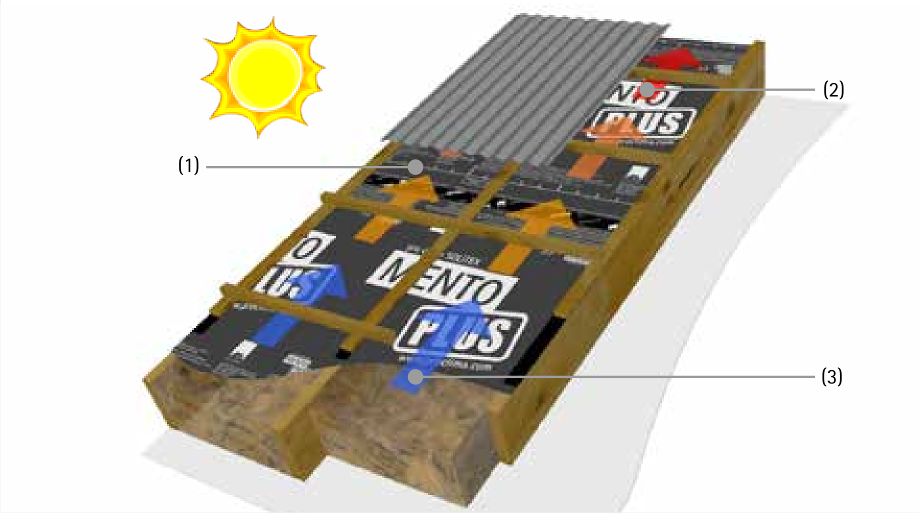


Figure 7.19: ASV is solar powered ventilation. Heat from the sun shining on the roof cladding, warms up the air beneath the cladding and induces a flow that moves the air upwards towards the ridge, while drawing in more air at the soffit. *Specific products may vary. Sun heats up roof cladding, (1) Heat transferred to air below, (2) Warm, buoyant air moves up the inclined air gap, (3) Cool air drawn in at eave

Truss roof

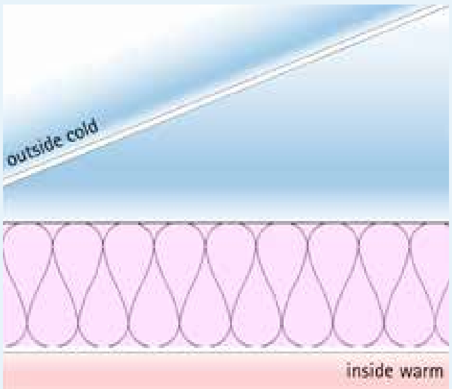


Figure 7.20: Truss roof – In winter, the external cladding systems & attic void will become colder than the internal linings on the inside of the insulation systems.

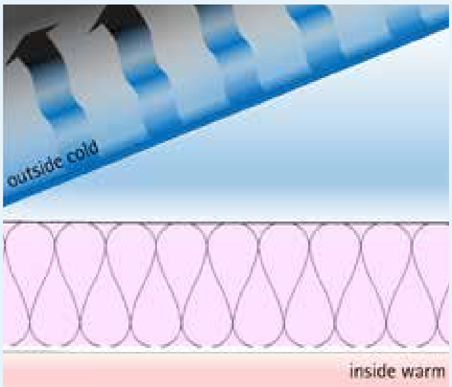


Figure 7.21: Truss roof – Night sky radiation can cool the external cladding system by as much as 10 °C below the ambient outdoor air temperature, further cooling the attic void.

Skillion roof

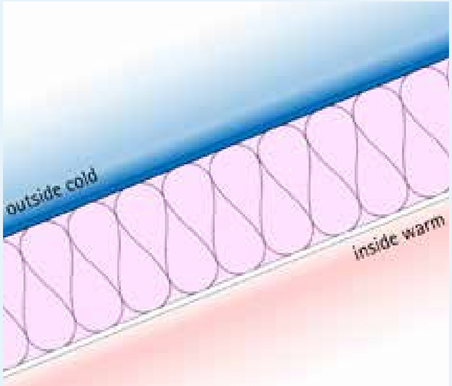


Figure 7.22: Skillion roof – In winter, the external cladding systems will become colder than the inside lining of the insulated skillion roof system.

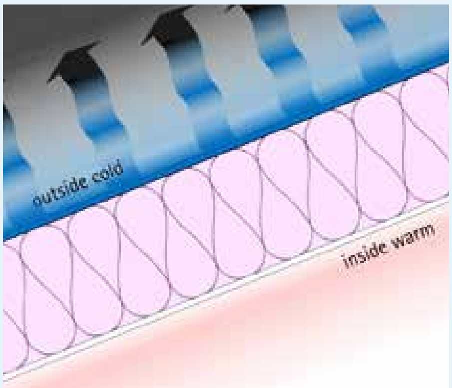


Figure 7.23: Skillion roof – Night sky radiation can cool the external cladding system by as much as 10 °C below the ambient outdoor air temperature, further cooling the outer layer of the insulated skillion roof system.

Figure 7.24: Early hours of the morning condensation due to night sky cooling [87]

Figure 7.25: Night Sky Radiation can reduce roof surface temperatures to below zero, causing frost, even when ambient air temperature is above zero degrees Celsius [88]

7.2.7 Benefits of Above Sheathing Ventilation (ASV)

Various building science studies from around the world have found that no matter what the roof cladding type, there are significant benefits to providing ventilation between the cladding and a secondary weather-tightness layer using battens and counter battens.

The three main benefits of ASV are:

- The counter battens enable free drainage of water on the membrane or the underlay boards.
- The air exchange reduces overheating of the attic, regardless of the colour of the roof cladding, thereby reducing the cooling demand of the building while creating more comfort internally.
- Air movement in the layer helps to remove any moisture that might accumulate either via water vapour permeating from the interior of the building, or from dew condensing from ambient air entering the cavity.

7.2.8 Design for effectiveness

Up until now, we have been designing and constructing roofs with adaptations to address symptoms. New Zealand has relied on roofing underlay materials to absorb inevitable moisture on the underside of roofs for decades. For us in Australia it is common to simply rely on mass movement of air in the roof to try to dry out the condensate faster than it accumulates or to use vapour barriers and compressed fibrous insulation against long run metal roofing to try to manage heat and moisture. But there is a better way.

By understanding what is going on in our roofs, we can design systems that keep our buildings dry, healthy and durable. The science shows that ASV makes sense.

In chapter 2 we have been discussing all the paths of moisture transport in, out and through our building construction in general. Chapter 7.3 & 7.4 takes a closer look and goes into more detail about how water can get into our roofs and how we can get rid of it, the importance of the sun and how we deal with heat, and we'll explore the all-important details of how to design and construct eaves and ridges for effective ventilation.

7.3 Winter performance

The two main hygrothermal performance characteristics for winter are the thermal heat losses and managing condensation on the underside of the roof cladding and/or within the assembly. Even when a climate is not extremely cold roof surface temperatures may still be much colder than you think.

7.3.1 Extra-terrestrial effects – night sky radiation

Night sky radiation is a super powerful effect where energy is sucked towards outer space out of our roof cladding. It can result in super cooling of the roof surface down as low as 10 °C or more below ambient air temperature.

Clouds have an insulating effect on the earth's surface, much like a big blanket. When the sky is clear this blanket of insulation is effectively removed, and long wave radiation is relatively free to emit energy back to space. The resulting net energy loss is most pronounced on surfaces facing the sky such as roofs and is most obvious at night-time when the energy flowing out to space is not balanced by any solar radiation. (Figure 7.20 – 7.25)

7.3.2 Water vapour on the inside

The human body is moist, made up of 50 - 70 % of water depending on physiology, gender and age. Respiration and perspiration release water vapour from our bodies into our abode. Compounded by other routine activities, such as cooking, cleaning & bathing, we put plenty of water into the interior environment of our buildings.

Having water on the inside of our buildings in the wrong place or at the wrong time will cause problems because we are not the only residents of our blue planet that have evolved to make use of water.

Water makes things grow. From plants to humans and everything in between, including fungus and mould. Life on planet Earth (and in our homes) relies on moisture to thrive. If you take moisture away, living organisms such as mould cannot grow (Figure 7.26). The roofing by which we protect ourselves needs to be designed to withstand the external forces of nature (wind, hail, snow, rain and humidity) while also not trapping water vapour from inside.

Material selection is important. Some manufactured board materials are extremely mould sensitive, particularly those containing wood compounds, which mould likes to feed on. If the moisture and the food sources are limited, then mould has less chance to thrive, but our buildings tend to have an abundance of cellulosic food. Timber and the paper backing of plasterboard all contain cellulose. If we can't remove the food, it's even more imperative that we avoid and remove moisture. Dry assemblies are healthy assemblies and keeping materials warm helps, to keep them dry.

7.3.3 Water in between

Water on the outside of our buildings is relatively easy to protect against. With respect to roofs, deflection is the primary line of defence. This relies on the shape and integrity of the cladding material. Beneath the cladding, we implement drainage as a secondary line of defence against any liquid water that might get through the cladding especially under sever driving rain conditions.
Water vapour on the inside of buildings is theoretically easy to manage with extractor fans and good ventilation. Unfortunately, most Australian homes don't manage internal humidity very well. This makes for unhealthy indoor living conditions and adds a potential moisture load to the roof structure of the building. If this moisture is allowed to reach the cold surface beneath the roof cladding, it is likely to condense into liquid water causing a mini rain shower inside the roof assembly.
The moisture in between the inside linings and outside cladding of our buildings can pose the biggest risk. This interstitial moisture is a problem because:

- Prolonged moisture in the structure can cause a lot of damage.
- Mould growth facilitated by moisture can affect the health of the building occupants.
- In a lined and clad house, interstitial moisture is invisible. (Figure 7.27 – 7.32)

7.3.4 Pressure, pores and perforations

There are many mechanisms by which air and water vapour can move through walls, roofs and floors to increase interstitial moisture. Vapour pressure is one such mechanism. The pressure of water vapour on one side of any boundary is relative to the density of water vapour molecules suspended in the air. A difference in vapour pressure will cause moisture to move in one direction or the other. We describe this pressure difference as a gradient.
We're very familiar with the force of gravity pushing an object down a physical gradient. Think of a ball on a see-saw. When the see-saw tips, the ball will roll downhill. If the see-saw tips back again, a gradient is created in the opposite direction and the ball will roll back to its original position.

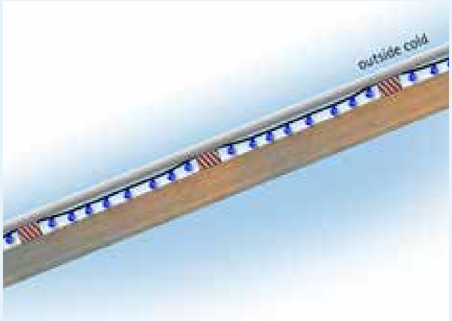


Figure 7.26: Having water on the inside of our buildings in the wrong place at the wrong time is when problems start to occur.

Truss roof

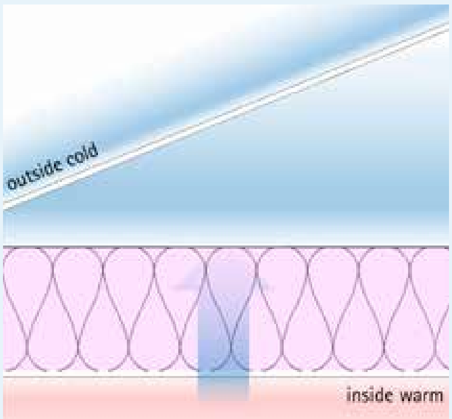


Figure 7.27: Water vapour from inside the house can diffuse upwards through the ceiling and insulation layers.

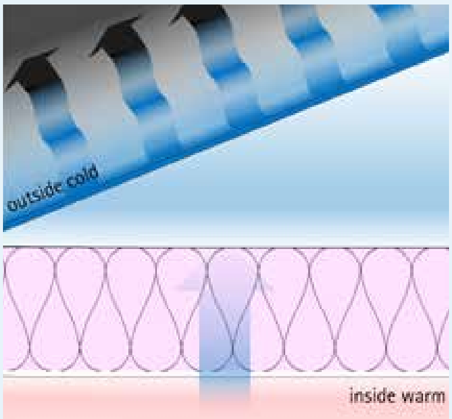


Figure 7.28: Night sky radiation can cool the cladding by as much as 10 degrees Celsius below the outdoor ambient air temperature.

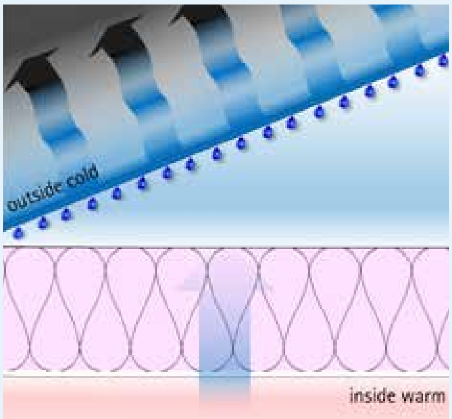


Figure 7.29: Condensation on the inside of the cladding assembly.

Skillion roofs

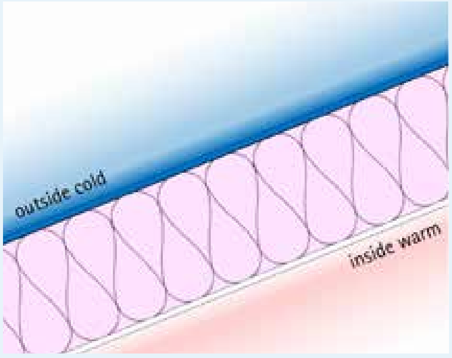


Figure 7.30: Water vapour from inside the house can diffuse upwards through the ceiling and insulation layers.

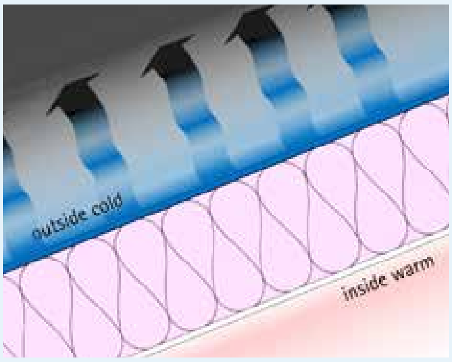


Figure 7.31: Night sky radiation can cool the cladding by as much as 10 degrees Celsius below the outdoor ambient air temperature.

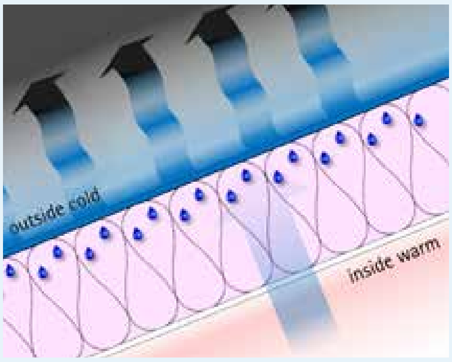


Figure 7.32: Condensation on the inside of the cladding assembly.

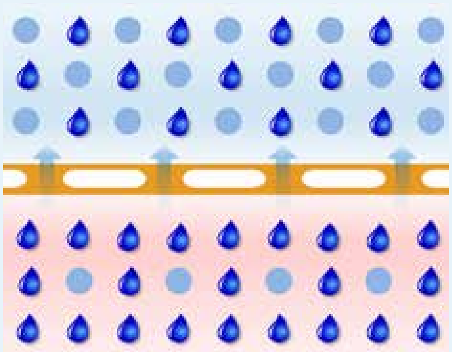


Figure 7.33: Vapour will diffuse through materials from an area of higher vapour pressure (below) to an area of lower vapour pressure (above). When it's relatively warm and humid inside a building, there is a prevalence for vapour to diffuse into the roof assembly.

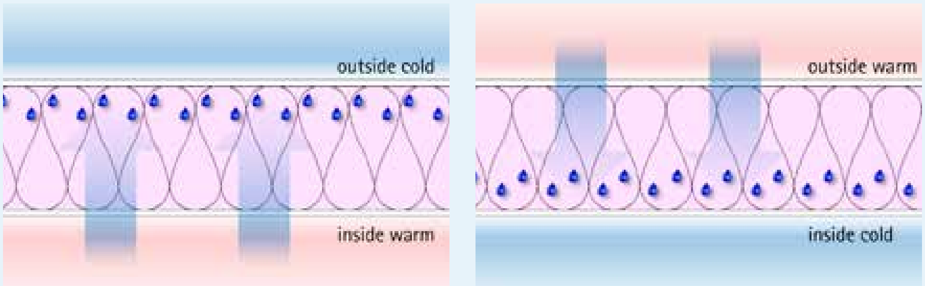


Figure 7.34: Water vapour will diffuse through materials and air to the coldest place. This may be outer most material layers in winter and the inner most material layers in humid summer conditions.

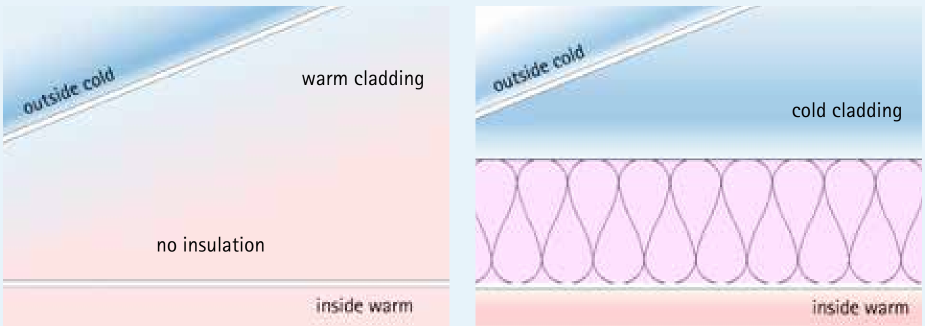


Figure 7.35: What used to be and what is now. Changing construction system dynamics due to insulation. Surfaces that were kept warm by energy inefficiency, such as immediately below the roofing materials (left) are now colder (right).

We're also pretty familiar with the concept of gradients when it comes to heat and wind. Heat energy always travels from a warm source to a cold source. Wind is air moving from a place of high air pressure to a place of low air pressure.

Vapour pressure follows the same laws. Moisture in the form of vapour will always travel from a place of high vapour pressure to a place of low vapour pressure (Figure 7.33). Because warm air can hold more moisture than cold air, the warmer side of our building envelope usually has a higher vapour pressure than the colder side. Therefore, in winter and during the night, the vapour pressure gradient is such that moisture from the inside of our buildings is pushing through the envelope to get to a place of lower vapour pressure on the outside. (Figure 7.34)

7.3.5 Greater gradients

Moisture within the roof structure of our buildings has become more of an issue in the last few decades because we've increased the pressure gradient. We have effectively tipped the see-saw higher.

When our buildings were full of gaps and holes, then air, moisture and heat were relatively free to move in and out. This was uncomfortable, so we added insulation which increased the temperature gradient (see Figure 7.35).

Building materials and practices have also created more sealed envelopes. This is a good thing when it is done with intention and with consideration for vapour control (discussed in chap. 2.1 and later), but if air sealing is done accidentally, in the wrong position and without allowing vapour to move out of the envelope, we end up with problems.

7.3.6 Heat and moisture in motion

Weather on the outside and human activity on the inside move heat, moisture, and air all of which can then move through the structure of our buildings.

- Vapour diffuses through all permeable construction materials, e.g. roofing membranes.
- Liquid is transported through all porous construction materials, e.g. masonry, timber.
- Air moves by convection through and within cavities, including ventilation cavities between roof cladding and substrates.
- Vapour travels with air, through unintentional gaps and cracks, particularly through ceiling penetrations.

- Moisture can be stored in most roof construction materials such as absorbent membranes, timber and insulation material.
- Heat radiates between materials and to the sky.
- Heat conducts between materials and air layers.

All these forms of energy and mass transfer need to be considered when analysing the drying potential of a roofing system. We can do this using computational hygrothermal tools such as WUFI® to look at the combination of heat and moisture movement through all the materials that make up a roof system.

When we understand these flows and design appropriately, we can create a roof system that responds predictably to the known forces of physics.

7.3.7 The water vapour super-highway

Counter-intuitively, adding water vapour to air actually makes that body of air lighter. Moist air is less dense and therefore more buoyant than dry air 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. [90]

Interstitial moisture accumulates when we construct roofs in a way that allows moisture to only go part of the way through the building envelope before it gets blocked. Large holes such as unsealed gaps and small holes such as intentional perforations in non-permeable materials, are examples of such pathways for moisture laden air. Warm humid air wants to go upwards, and it will find gaps and cracks in the ceiling linings.

"The ceiling contains gaps, such as around loft hatches and service penetrations, which provide routes for air to flow from the occupied space into the loft [attic/roof space]. There are also more complex airflow routes; for example, through wall cavities and behind lining systems. Heat and moisture are generated by the normal activities of the household within the occupied space of the house below the ceiling, raising the temperature and vapour pressure above the ambient conditions outside. Some of this heat and moisture leaves the living areas of the house, passing through the ceiling into the loft [attic/roof space] by a combination of conduction and diffusion, and air movement. This movement contributes significantly to heat loss from the house and leads to a risk of condensation within the loft [attic/roof

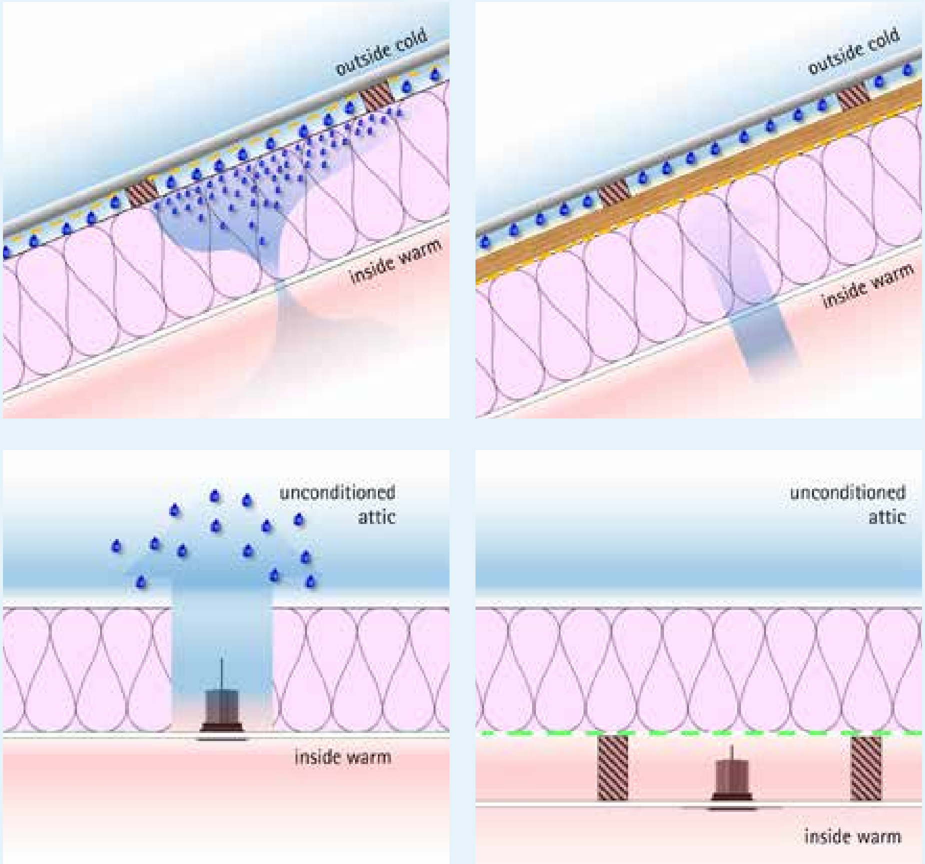


Figure 7.36: INTELLO® PLUS Intelligent Air Barrier system at the ceiling line prevent unwanted additional water vapour from entering the roof space of insulated construction systems, thereby blocking the water vapour superhighway.

To find a WUFI® professional, go to www.wufi.com.au

Figure 7.37: Cold surfaces and moisture laden airflow lead to condensation and fungal growth. [91]

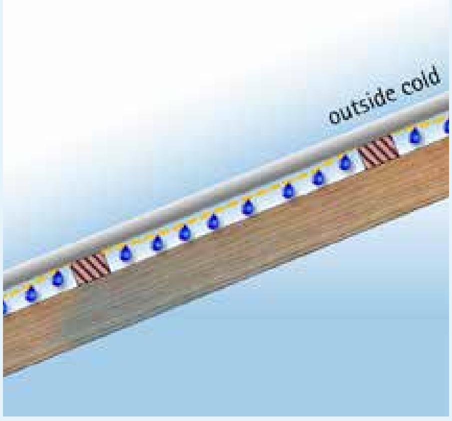


Figure 7.38: Membrane in contact with the cladding means the membrane is the same temperature as the cladding. Note: In Australia a low emittance aluminium foil surface will drive the cladding temperature even lower than compared to a high emittance surface.

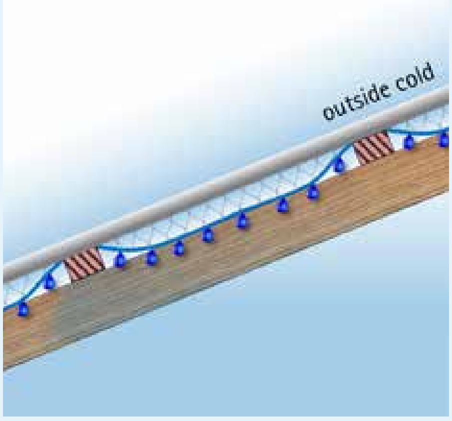


Figure 7.39: Insulation pushed up against the cladding means that the cladding will get colder under the influence of night sky radiation than it otherwise would with no insulation as there is less warming from below. This increases the vapour pressure force into the blanket towards the cladding surface.

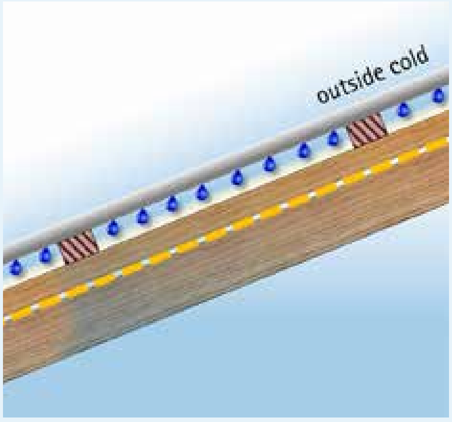


Figure 7.40: Above membrane ventilation introduces air that will have a warming effect on the roof cladding because the ambient air being drawn in is warmer than the super cooled roof cladding.

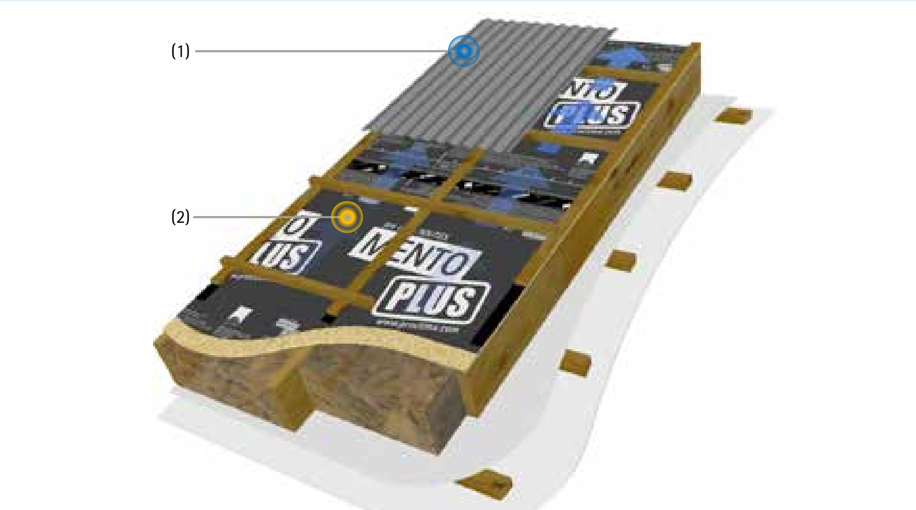


Figure 7.41: Roofs must be designed and constructed to withstand temperature and pressure effects. Above Sheathing Ventilation (ASV), utilises wind effects and buoyancy of water vapour like the upward movement of clouds, to remove water vapour from the roof assembly and helps to warm the sub-roof on cold winter nights. (1) Cladding temperature (1st line of defence), (2) Sub roof temperature (2nd line of defence)

space]. Reducing the airflow through the ceiling as far as is practicable will both save energy and reduce the risk of condensation." [92]

Ceiling penetrations for lights, vents, speakers, and other services are basically unavoidable. A properly designed and dedicated Intelligent Air Barrier (IAB) above these services can achieve outstanding outcomes by controlling

7.3.8 Above sheathing (membrane) ventilation - countering counter radiation

The force is strong with night sky radiation. Despite many climate regions in Australia not being "cold" by international standards we need to consider the fact that the actual roof cladding temperature could be up to 10 °C cooler than the minimum reported air temperature. This completely changes the way we need to consider our roofs. We cannot stop night sky radiation from cooling the roof surface. All we can do is design to manage its effect.

"The surface temperature of the sub-roof beneath the ventilation layer and the tiles is one of the most important factors for the hygrothermal performance of pitched roofs. The air layer between tiles and sub-roof and the air exchange with the outdoor air influence the heat transfer and therefore affect the moisture level inside the roof construction." [93] (Figure 7.38 – 7.40)

In winter and at night, the coldest surface in a roof assembly will be the cladding. However, it can also act as a radiant shield to protect the roofing layers below from excessive overcooling from the powerful effect of night sky radiation.

By separating the membrane from the cladding, ambient air is introduced between the first and second lines of defence. While we might still call this night-time air "cold", it's not as cold as the cladding which has been supercooled by night sky radiation.

Therefore, the ambient air will have a slight but significant warming effect on the roof cladding.

"During night-time, the long-wave radiation losses mainly affect the cladding and lead to a notable overcooling below the outdoor air temperature, while the surface temperature of the sub-roof remains close to the outdoor air temperature." [93] (Figure 7.41)

7.3.9 Water vapour and cold surfaces

Water vapour will readily condense onto cold surfaces, or within the pores of cold materials, resulting in increased material moisture content. If these cold surfaces and materials are located towards the outer (cold) side of the roofing system, there is risk of mould growth and timber rot because the high moisture content levels are likely to be sustained (Figure 7.42). To avoid this, a drainage path for condensate is mandatory, not optional. (Figure 7.43 – 7.45). Aluminium foil creates a condensation plane where condensate can form day and night on the inside surface of the sarking system.
A lack of vapour permeability and zero sorptive capacity on the membrane means that a perfect condensing surface is provided (Figure 7.42 A). Water can drip off aluminium sarking onto ceiling insulation. On a 23° slope roof water will start to run down a roof at 150 g/m² of condensate. [94] (Figure 7.42 B) High humidity in the roof space, inclusion of a condensing surface and lack of moisture egress results in mould growth on foil surfaces (Figure 7.42 C).

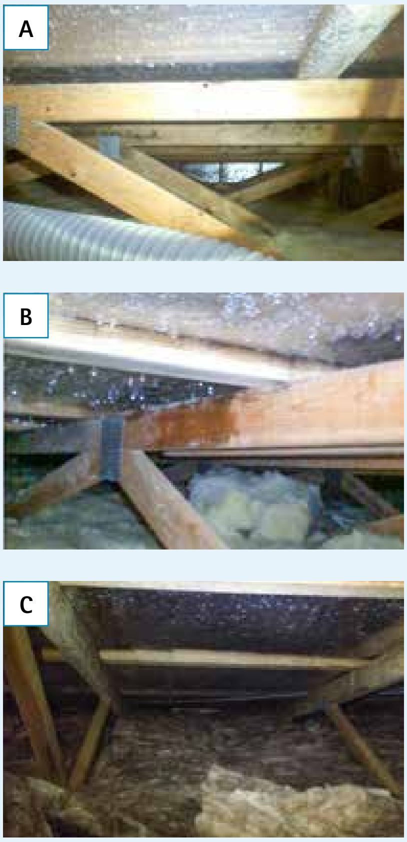


Figure 7.42: Moisture related issues on aluminium foil condensing surfaces [74]

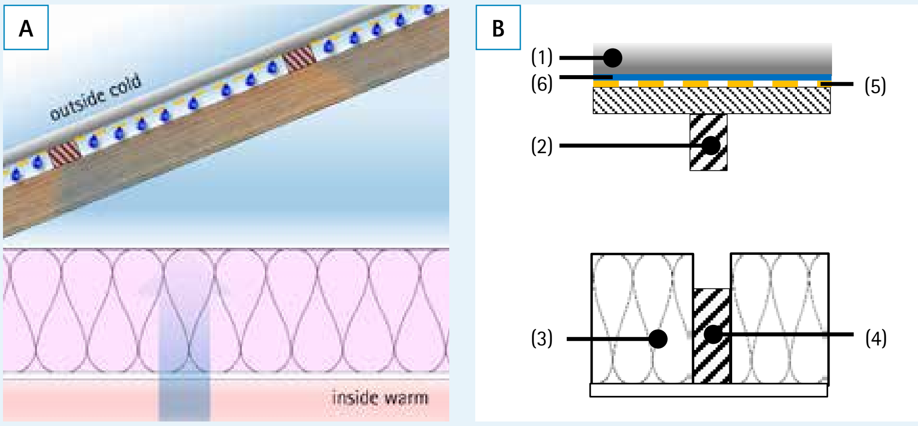


Figure 7.43: A: Membrane placed hard up against the roof cladding provide a direct conductive pathway for energy dropping the surface temperature of the membrane. The membrane itself becomes a condensing surface. Aluminium foil membranes have little if any absorbency capacity. On a 23° slope roof water will start to run down a roof at 150 g/m² of condensate. [94] In New Zealand, the membrane itself acts as a desiccant to absorb condensate and prevent dripping. It is required to have at least 150g/m² of absorbency. [95] SOLITEX MENTO® products can hold up to 380 g/m² of water. B: Membrane in contact with metal roof: (1) Metal sheet roof, (2) Truss top chord, (3) Bulk insulation, (4) Truss, (5) Membrane against roof cladding: SOLITEX MENTO®, (6) condensing plane

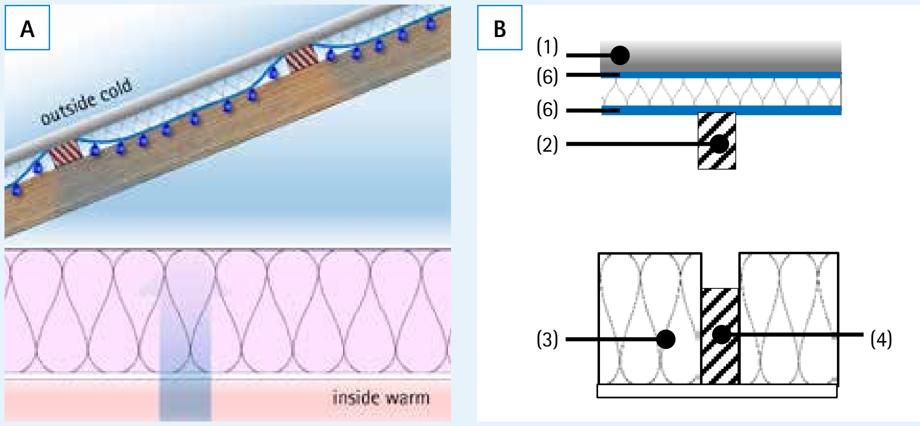


Figure 7.44: A: There are now two condensing surfaces; the foil and the sheet metal. B: Blanket compressed under metal roof: (1) Metal sheet roof, (2) Truss top chord, (3) Bulk insulation, (4) Truss, (5) Foil Vapour Barrier, (6) Condensing plane

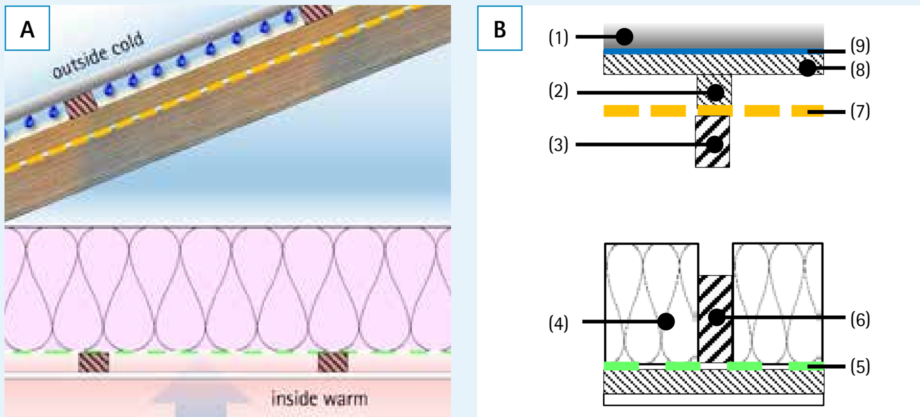


Figure 7.45: A: Above Sheathing (membrane) Ventilation has several benefits: The cold outdoor air is not actually cold relative to the supercooled cladding, it is warm. The ventilation air acts to warm the cladding and membrane surface reducing the risk of moisture damage and improving energy efficiency by reducing energy losses. An Intelligent Air Barrier (IAB) at the ceiling line prevents moist air going up into the roof space through any superhighways created by ceiling penetrations. B: (1) Metal sheet roof, (2) Counter batten, (3) Truss top chord, (4) Bulk insulation, (5) INTELLO® PLUS, (6) Truss, (7) SOLITEX MENTO®, (8) Fixing batten, (9) condensing plane

External humidity

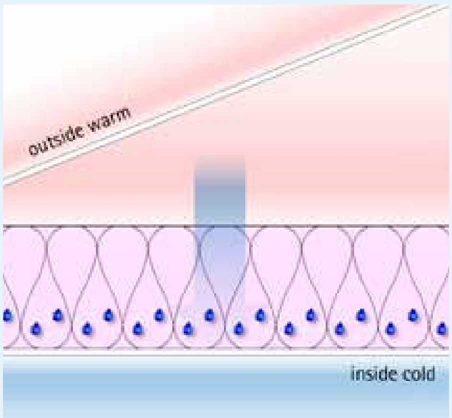


Figure 7.46: In high humidity climates, tropical and subtropical, the amount of water vapour attracted to cool interior lining in air-conditioned buildings will result in elevated moisture content in the plasterboard and conditions conductive to mould.

Figure 7.47: Mould growth on ceiling in Cairns from humid air reaching the back surface of the cooled plasterboard ceiling [97]

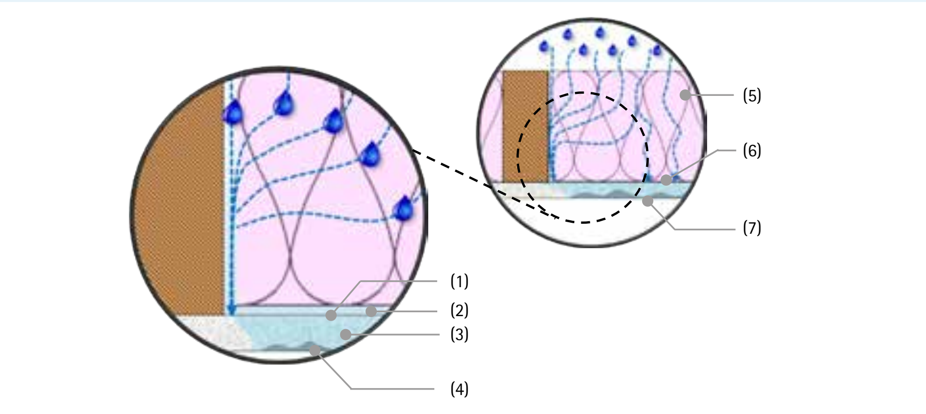


Figure 7.48: Fibrous insulation has virtually no resistance to water vapour. In this case it may be beneficial to seal the attic in air-conditioned buildings. The membranes used on the roof system will need to be selected accordingly and special advice sought. With professional hygrothermal advice it may be beneficial to utilise sealed roof constructions in high humidity climates. (1) Spots of mould on paper facing, (2) Humid air, (3) Gypsum core saturated with liquid water, (4) Patches of mould infringing on gypsum core, (5) Batt insulation, (6) Paper facing, (7) Semi gloss paint

7.3.10 Building physics reversed (tropics)

The rules of physics cannot be broken but the forces may reverse. Seasonally this can drive water vapour pressure the other way meaning that the plasterboard adjacent to air-conditioned environments becomes the cold surface. This is a particular issue in humid and tropical climates where air transported water vapour and diffusion processes may result in attraction of water vapour to internal cold plasterboard layers covered in cellulose paper facings. Moisture, food source and warm temperatures are a perfect environment for mould growth (Figure 7.46 – 7.48). With professional hygrothermal advice it may be beneficial to utilise roof constructions which are sealed using the exterior WRB in high humidity tropical climates. For optimum protection from strong wind forces rigid sheathing with SOLITEX ADHERO® applied over can provide sufficient vapour resistance.

7.3.11 Attic space – controlling the uncontrollable

In truss roof systems there is a large air void. In most cases it is prudent to ventilate any large air voids on the outside of the insulation layer. This is because large air voids are unpredictable. Water vapour will readily redistribute to the coldest places in the assembly.
The mighty truss still dominates in Australia and is not going anywhere anytime soon. The best we can do is to remove as much moisture as possible within the large air void via ventilation. A roof ventilation strategy needs careful consideration:
“Because the primary purpose of ventilating roofs is to remove moisture, the design and location in the roof should obviously allow for good airflow. Outlet vents, such as ridge vents, must only be installed in conjunction with inlet vents. Inlet vents should be dimensioned slightly larger than the outlets to ensure all makeup air comes from outside and is not drawn from inside the building.” [96]
The key to ventilating a roof is having sufficient opening area to allow air into the attic space. There are various thresholds internationally. For guidance, an open area ratio of 1:300 implies 1 m² of vent opening area is required for every 300 m² of insulated ceiling.
“The size of the ventilation is often described as a ratio between the net free opening area of the vents to the area of insulated ceiling.

While ratios ranging from 1:150 to 1:600 can be found, 1:300 seems to be a frequently specified fraction." [96] (Figure 7.49)

7.3.12 Construction process – temporary protection

When constructing a roof with ASV, the battens and cladding may be installed at different times. Therefore, there is a risky period where the WRB may get rained on. In this situation it is necessary to have good seals on all penetrations. (Figure 7.50) There is moisture within the structure of buildings to begin with, especially in brand new buildings. Trusses and rafters are supposed to be dry but it's never completely dry (20 % moisture content, by definition means that at least 20 % by mass is water), and timber is often allowed to get saturated before buildings are properly closed in (Figure 7.50 & 7.51).
Other materials like concrete are also massive sources of moisture for new buildings. If the ceiling is not completely sealed, then these moisture sources will contribute to the moisture load of the roof. Even in the best-case scenario where the framing and materials are kept "dry" during construction, moisture will always be trying to get in. We therefore need to be designing roofs that allow for drying. (Figure 7.49)

7.3.13 Above Sheathing Ventilation (ASV)

Above Sheathing (membrane) Ventilation allows us to fight mould, timber rot and corrosion by protecting against the exterior weather while increasing the drying potential to maintain a durable and healthy building.
Properly implemented ASV assists by:

- allowing the structure to remain dry during construction,
- preventing water leaks in extreme weather events during operation,
- preventing the accumulation of internal water vapour in the structure during normal operation (interstitial condensation) and
- reducing excess heat load from the sun (see section 7.4)

Figure 7.49: In addition to ventilation of the attic space is preferable in most circumstances.

Figure 7.50: Leakage of water through fixing penetrations prior to cladding when TESCON® NAIDECK nail sealing tape was not used [98]

Figure 7.51: Framing timber is often allowed to get saturated on building sites before buildings are properly closed in and protected from weather [99]

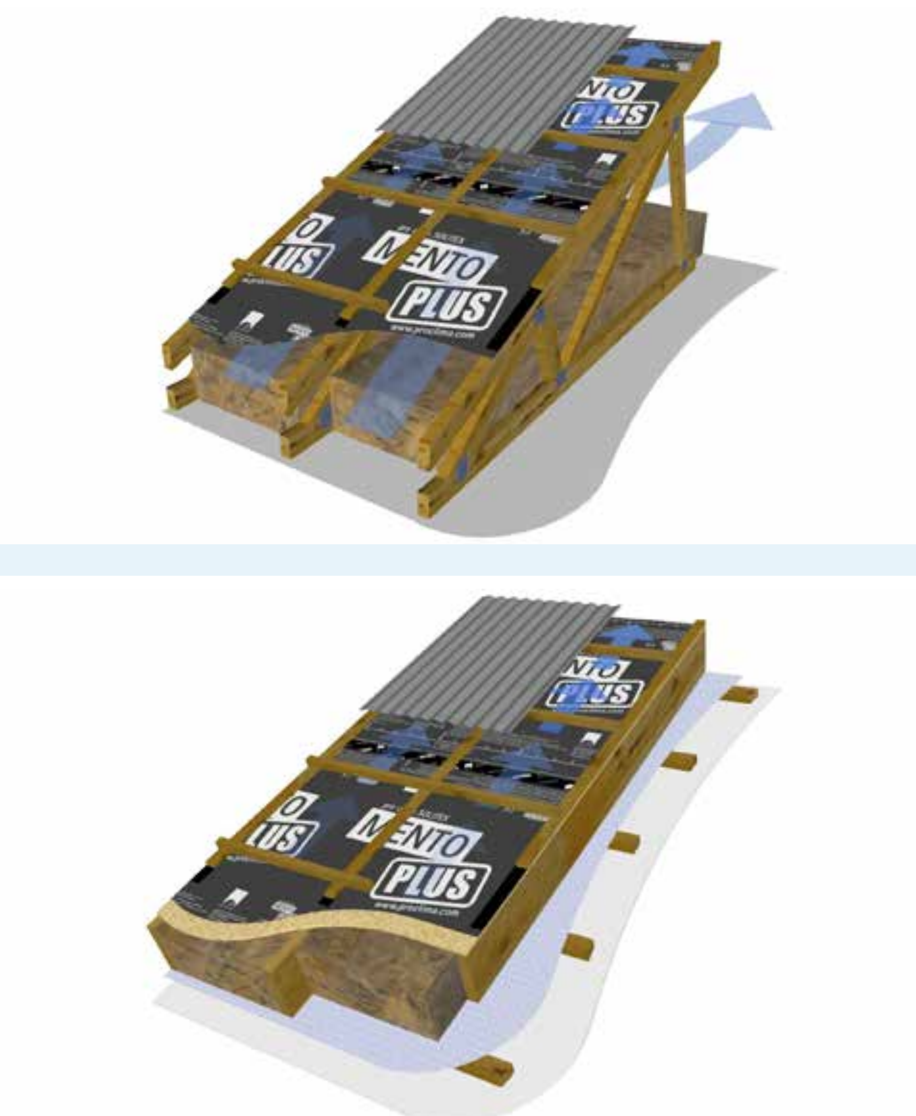


Figure 7.52: The best place for controlled, contained roof ventilation is between the cladding and the membrane. Large air void on the outside of insulation layers (attics) are best ventilated as well.

7.3.14 Living with water

Without water people die. Without moisture, mould and timber destroying fungi cannot thrive. Keeping water out of the building envelope and increasing the drying potential is a simple formula, in theory. In practice, the secret to a dry, durable roof is to have specific ventilation in a specific location for a specific purpose. The best place for controlled, contained ventilation is between the cladding and the membrane. (Figure 7.52)
Buildings are not submarines. We should design and construct our buildings with an understanding of how water, vapour, air and heat will move in, around and through the building enclosure. When we understand and apply the laws of physics, we can successfully construct safe, healthy places to enjoy our blue planet in comfort.
ASV facilitates drying of the roof by using similar physics that create rising clouds on the surface of the earth. A layer of moisture laden air underneath the roof cladding is warmed by the morning sun on the roof. This buoyant air moves up the cavity towards the ridge and is replaced at the eave by cooler air. If any liquid water does accumulate on, or leak into the underside of the roof cladding, drainage is facilitated by the unimpeded pathway on top of the roof membrane. Meanwhile, moisture vapour is carried out of the system by the moving air. In this way, the system does not rely so much on diurnal absorption and desorption of moisture by the roofing underlay.

7.3.15 Water and heat

This section has covered the impact of water from the outside, the inside and within our buildings. We are wet beings living on a wet planet, but we want our buildings to be as dry as possible in order to be durable and to provide healthy places to live, work and play. ASV is a method of constructing roofs to keep the structure dry using proven building physics.

7.4 Summer performance

All the heat reaching the earth's surface is from direct radiation which occurs in the line of sight between the sun (heat source) and your roof (receiver).
During midday on a typical sunny day, there is approximately 1 kW/m² of solar radiation on a roofs surface, and between 20 percent and 95 percent of this radiation is absorbed based on the different roof colours. [101] (Figure 7.53) Once the heat has entered our atmosphere it is absorbed into roof cladding materials at the earth's surface, by utilising purpose built cavities we have the ability to purge the majority of this heat using air movement.

7.4.1 Managing radiative heat vs convective heat removal

In 1960s Australia "high-tech" low emissivity aluminium foils were popularised. These have been applied to construction systems for decades and have become engrained in the psyche of Australian construction industry as the go to solution to improve summer performance. This is a solution formulated with a myopic view of climate and seasonal variations that take place on our blue planet. Standard approaches are biased for summer performance compromising roofing systems which can exacerbate condensation in winter. This manifests as unnecessary moisture related issues when the roof becomes excessively cold in the cooler months of the year. (As discussed in previous section 7.3)
In NZ, industry emphasis is placed on improving guidance around moisture safe design and is therefore more progressed than Australia. The use of vapour permeable membranes and ventilation to expel moisture is commonplace. However, the summer effects of heat flow down have been paid less attention.

7.4.2 Convection removes heat (and moisture)

ASV is the superhero, it allows for removal of heat via convective heat exchange. The key to preventing heat flow down into your roof is utilising controlled, purpose-built convection pathways behind the cladding, previously defined as Above Sheathing (membrane) Ventilation. This removes moisture in winter as well as being highly effective in removing heat in summer.

7.4.3 Heat islands

Altruistic design choices can lead to an overall reduction in the peak summer temperatures experienced in urban areas. Choosing heat reflective colours (light colours) and increasing tree foliage are well researched and proven strategies. We know black is hot and all cricketers know white stays cooler. White roofs increase the albedo, or simply reflect more of the incoming radiative heat from the sun with cool colours. Some roof cladding materials can achieve up to 77 % solar reflectance.
This means only 23 % is absorbed by the cladding. The regulations in Australia allow less insulation for lighter colour roofs in warmer climates that are deemed "summer dominant" climates.
In 2020 Santamouris et al. [102] calculated the magnitude of overheating in Sydney, Australia, at close to 9 °C, which causes a cooling penalty of up to 16 % and an increase in the indoor overheating levels of up to 56 % and to combat this "Reflective surfaces can decrease the peak ambient temperature in Sydney by up to 1.5 °C, [...]. Therefore, the deployment of tested and durable reflective materials is of the utmost importance, since weathering, soiling, chemical stress, and biological growth can result in considerable optical ageing and an increase in solar absorbance." * (Figure 7.54)

7.4.4 Roof colour – A double-edged sword

Almost all climate regions across Australia have a summer and a winter. We need solutions that can handle all extremes. Lighter coloured roofs induce cooler temperatures in summer and lower the average roofing temperature and sub layer temperatures in winter. This potentially exacerbates moisture related issues in winter unless properly designed for with vapour control layers and protection from air transported and water vapour diffusion effects from the internal conditioned space.

7.4.5 The umbrella academy

A parasol is a lightweight umbrella used to give shade from the sun. In architecture a parasol roof is a light roof that shades the main structure from the sun. It has been used for decades by architects in hot climates to improve summer comfort by blocking the sun and removing heat by convection from the underside of the parasol. Although

Figure 7.53: 1 kW/m² is the same heat energy as a 200 m² roof loaded with 200 of these heaters [100]

Figure 7.54: Over time the absorptivity of the roof will increase as the roof ages, surfaces dull and dirt, grime & lichens accumulate [103]

* Note: Estimations based on an Increase in the albedo of roofs from 0.1 to 0.6 and pavements from 0.08 to 0.4 for all of Sydney.

Figure 7.55: Examples of Parasol roofs, Left: Designed by Robin Boyd 1956. This house is an example of the architects courtyard style with a parasol roof. [104] Right: Cliff Face House, Fergus Scott and Peter Stutchbury Pittwater, Sydney [105]

Figure 7.56: Tile roof have always allowed for incidental air flow under the battens and tiles, but not necessarily with dedicated inlet and outlet openings. (1) Fixing batten, (2) Roof tiles, (3) Attic Ventilation (opening to ceiling area ratio 1:300); Tile fixing methods has always achieved a ventilated cavity by default. The membrane under the battens allows for an airflow pathway that helps to remove heat by convection. The air layer means the membrane stays cooler than when pushed hard against a metal sheet cladding material.

Figure 7.57: Purpose built air flow pathways allow heat to be removed before it reaches the insulation layers below. (1) Wind barrier creates an air cavity and chimney effect, (2) Shading (parasol) layer shades layers below from the sun

these roofs are often complex and generally reserved for architectural homes with larger budgets, the fundamental principles can be employed on small scale utilising convective air currents to remove large amounts of heat. (Figure 7.55)

If the parasol is a white heat reflective colour, then the parasol works even better to fight the sun. But we need to be conscious of the equal and opposite reaction in winter.

In many countries and for many years, pitched roof constructions with tiles made of clay or concrete used to be built with a ventilation layer underneath the tiles. At least the battens, which are needed to attach the tiles, typically create a thin air layer. [93] (Figure 7.56)

The air exchange reduces overheating of the attic during summer. This same historical usage of airflow under tile systems and the parasol roof can intentionally be combined and designed with a dedicated ventilation pathway. Regardless of the cladding or colour of the roof it will remove significant amounts of heat. (Figure 7.57)

7.4.6 Self-regulation

The hotter dark grey roof causes greater buoyancy-induced airflows; therefore, the ventilation scheme is somewhat self-regulating. The darker the roof, the hotter the roof, so there is greater buoyancy to carry heat away from the attic. [106] (Figure 7.58)

However, all in all a light colour roof with above sheathing ventilation delivers the best summer performance, but the penalty for a mid-dark colour may not be as high as you would think.

In 2006 research from Oakridge National Laboratories in the US found that “regardless of roof colour the stack effect ensures the system, is self-regulating. Darker roofs create a stronger stack effect removing more heat”. [106] (Figure 7.59 – 7.60)

The interesting part is that it was found “the heat flow crossing the roof deck of the dark-grey [roof] was just 70 % of the heat flow crossing the roof deck of the control [roof]” with both claddings having almost identical solar reflectance and thermal emissivity. It was concluded “the 30 % reduction in heat flow is due to above sheathing ventilation. [86]

By increasing the solar reflectance (r = 0.08 to 0.26), a further reduction of about 15 % of the heat crossing the deck of the control roof. Miller, Wilson, and Karagiozis (2006) therefore concluded that ventilating the deck is just as important as is increasing solar reflectance and may be the stronger player in reducing heat gain into the attic." [86]

Using a strategy of increased solar reflectance and above-sheathing ventilation resulted in a reduction of heat flow penetrating the attic floor by 70% during daylight hours, compared with the heat flow penetrating the attic floor of a roof with conventional asphalt shingles. [86]

Given that sheet roofing in Australia is available with just 23% solar absorptance this can be used in conjunction with ventilation strategies to further enhance this effect. With special attention to designs that protect against wintertime condensation.

7.4.7 Bigger is better (in summer)

The dedicated pathway beneath the cladding needs to include sufficient height and cross-sectional area for the air flow. The effective ventilation area is taken as the cross-sectional area created by the vertical counter battens (Figure 7.62 & 7.63). When promoting airflow under the roofing systems, this is a case of bigger is better. Larger vertical counter battens allow for higher volumetric air flow and better heat removal as a consequence. The bigger it gets the more like a full parasol roof it becomes. Miller and Kosny found "most important [was] the observation that as the cool colour tile is moved further away from the deck i.e. laid directly on the deck compared with offset from deck using a batten (19 mm), the roof's thermal performance improves". [106]

The behaviour is like a heat exchanger: the ambient air cools down the surfaces on the way from the eaves to the ridge and warms itself up; therefore, the surrounding surfaces are also warming up. Due to the rising temperature difference between the roof surface and the outdoor air and surroundings, the losses by long-wave emission and convection increase – the temperature difference curve flattens. [91] (See Figure 7.63)

The larger the unrestricted airflow pathway the cooler the cavity and the insulation below needs to do less work. (Figure 7.63)

Design thresholds for the inlets and outlets are also critical. For best performance in summer, it is always better to seek a strong ventilation strategy. This means utilising taller counter battens and larger inlets and outlets as to not restrict the airflow. The Central Association of the German Roofing Trade (Zentralverband des Deutschen Dach-

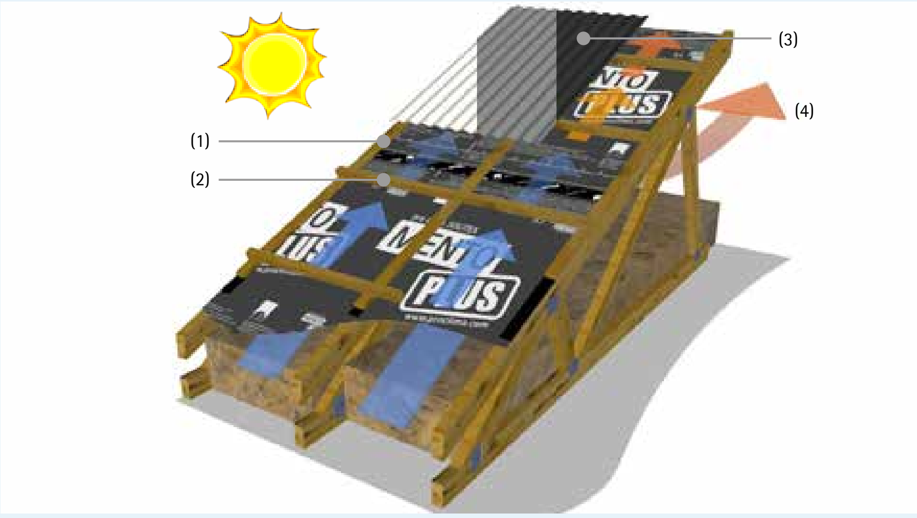


Figure 7.58: Self-Regulation effect of different absorptance roof colours. (1) Counter batten, (2) Fixing batten, (3) Roof sheeting, light, medium or dark, (4) Attic ventilation (opening to ceiling area ratio 1:300); A purpose designed and built ventilation pathway introduces cooler outdoor air which helps to counteract the daytime solar gains. Although the outdoor air is warm in summer it is still much cooler than the cladding helping to cool the membrane and reduce the overall heat flow down. Note: The above membrane ventilation requires a class 4 vapour permeable membrane for wintertime condensation control allowing the upward diffusion of moisture into the ventilated cavity where it can be safely expelled to outdoors.

Figure 7.59: With purpose-built cavity the counter battens define the ventilation crosssectional area. The type of cladding, metal or tiles is therefore irrelevant and only changes the batten spacing. [106]

Figure 7.60: Test roof At Oakridge National Laboratory [86]

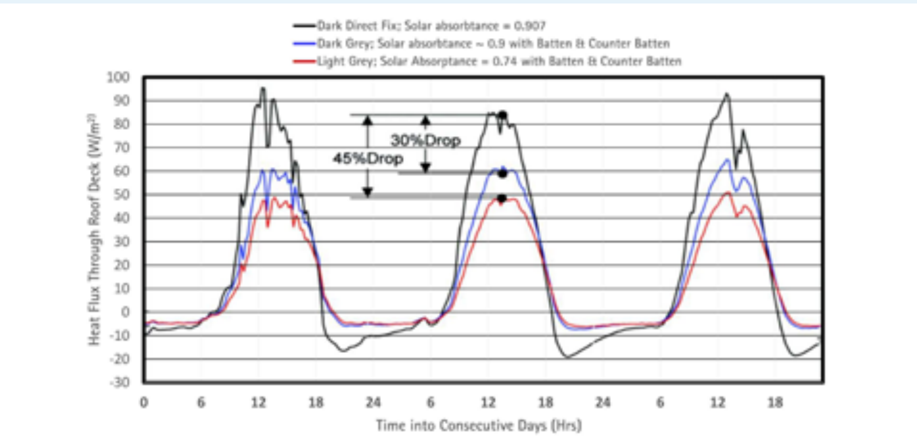


Figure 7.61: The effect of above-sheathing ventilation and solar reflectance for two metal roofs compared with a direct-nailed shingle roof. Stone-coated metal installed on batten and counter-batten systems. These roofs were offset from the roof deck by about ¾ in. (0.019 m) using a batten and counter-batten system. [105]

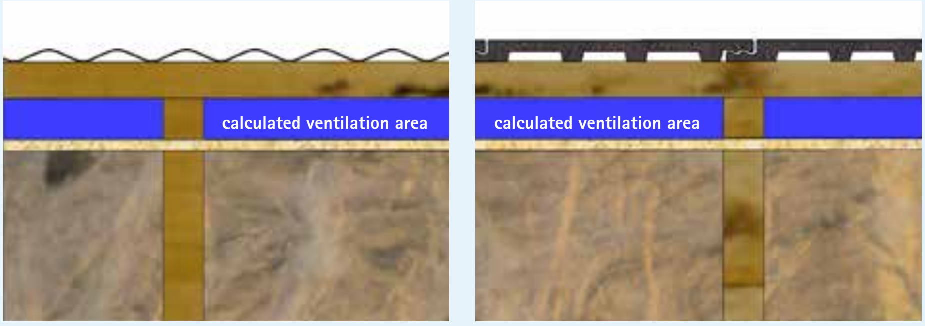
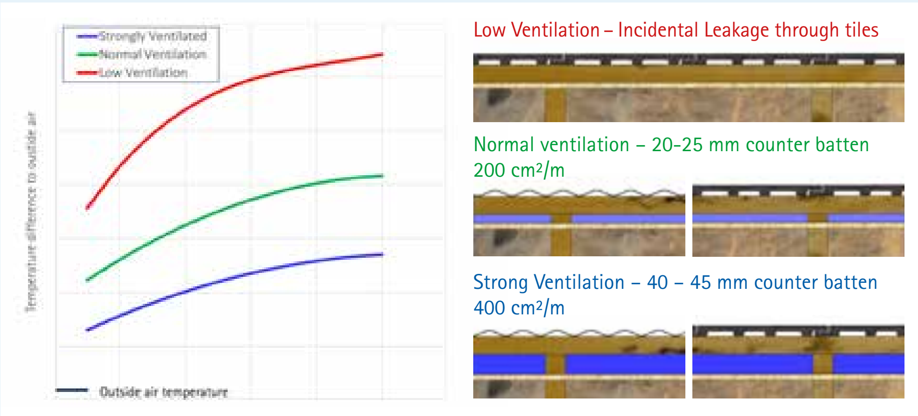


Figure 7.62: The height of the counter battens can be increased to enhance the airflow and heat removal in summer.



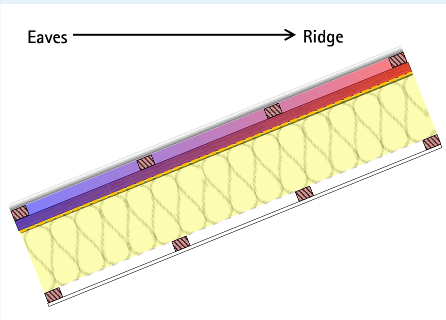


Figure 7.63: The effectiveness of the ventilation for removing heat is related to the counter batten height. Low, normal or strong ventilation can be designed. Adapted from [92]

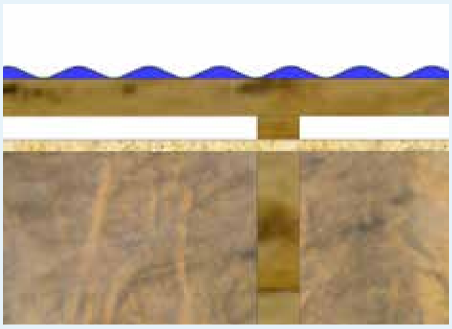


Figure 7.64: The corrugations in sheet metal will achieve ~ 60 cm²/m of roof ridge. The ridge caping fixed without dressing down into the corrugations can provide sufficient ridge opening area.

	Eave Inlet	Counter Batten	Ridge Outlet
Low ventilation – Incidental leakage through tiles	Not Specifically designed	None – Not an ASV system	Not Specifically designed
Normal ventilation	~200 cm²/m	Min. 20 mm high	~50 cm²/m
Strong Ventilation	~400 cm²/m	Min. 45 mm high	~100 cm²/m
	 [108]	 [109]	 [110]

Table 7.1: Inlet, Outlet and counter batten arrangements for different ventilation strategies. Structured ventilation includes dedicated inlets and outlets to achieve ventilation behind the cladding. Once ridge capping is placed it is possible to leave corrugation open to achieve 50 cm²/m.

deckerhandwerks) and DIN 4108-3 (thermal protection and energy economy in buildings) standard practice result in openings at the eave and ridge in approximately the ratios in Table 7.1 to achieve a low, normal, or strong ventilation strategy. These may form the basis of design thresholds which have been studied with specific above membrane ventilation strategies from Fraunhofer Institute of Building Physics for both winter moisture and summer heat removal. [89] (Table 7.1, Figure 7.63 & 7.64)
Note that the opening area is per linear meter of eave or ridge and needs to account for any reductions from insect, vermin or bushfire meshes and screens these may have anywhere from 10% to 90% open area ratios and will reduce the resulting inlet opening area.

7.4.8 Summer infiltration

Drafts are most often felt in winter and not often talked about in summer. Although summer drafts are of no concern to comfort they will reduce the overall effectiveness of the insulation system. Another aspect for the summer super solution is that warm/hot air from the outside of the insulation can flow unhindered through the insulation to the inside when an IAB is not properly sealed (Figure 7.65). It is of secondary importance how much heat arrives in the interior, the first priority is that the cells of air in the thermal insulation becomes warm and thus no longer provides it's full thermal insulation effect against heat. The consequence is uncontrolled heating of the interior – overheated rooms or excessive energy consumption and excessive energy costs.
From a building physics point of view, there are various reasons why warm air can penetrate the thermal insulation:

- **Pressure differences due to different temperatures**
  Air with different temperature creates pressure differences because warm air is lighter and rises and cold air is heavier and sinks. This causes air movement within the building and within the structure. The air escaping from the building through air leaks inevitably draws air from the outside (Figure 7.66 A) into the building and thus through the believed to be airtight construction to the inside. This is related to the whole building and also to component segments, such as a rafter field (see chapter 2.3).

- **Pressure differences due to wind influences**
  In the rarest of cases there is absolute calm. Even the smallest wind movements cause pressure differences and then also leads to air movement within the building and the component segments (Figure 7.66 B). If the air outside is warmer (here it is not the air temperature outside that matters, but the temperature on the outside of the building, i.e. behind the roof covering or façade), this warm air always penetrates the construction, i.e. also the thermal insulation, if there are air leaks.

Air always wants to balance itself and mixes, driven by pressure differences resulting from temperature differences and/or due to wind influences. It can sometimes move in the most diverse directions (turbulently).

No matter what causes air to flow in from the outside through leaks in the building envelope and thus penetrate the construction: If the air is warm (the decisive factor is the air temperature in the ventilated cavities behind the roof coverings), the thermal insulation heats up and thus loses its heat-insulating effect. The building consumes more energy for cooling and thus costs more money for air conditioning. An INTELLO® PLUS layer removes the ability for air leaks to deteriorate the insulation value.

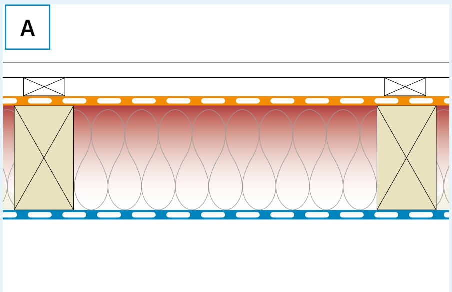


Figure 7.65 A: Cool rooms during summer heat: Airtight and windtight roof construction prevents heat flow by convection

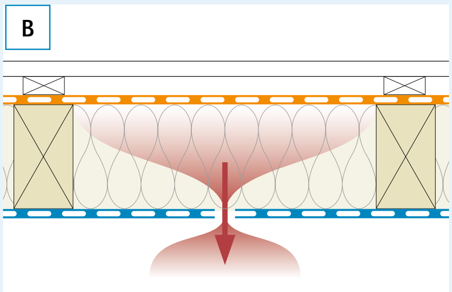


Figure 7.65 B: Overheating up due to air flow: non-airtight roof construction

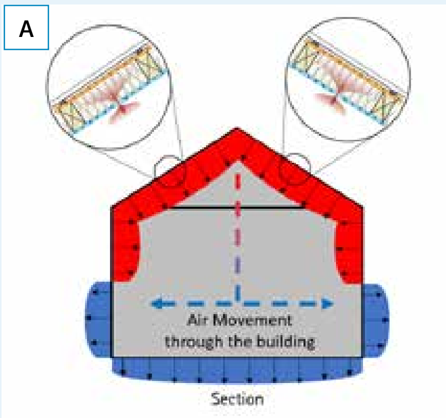


Figure 7.66 A: Cool air thermosyphon on a freestanding building

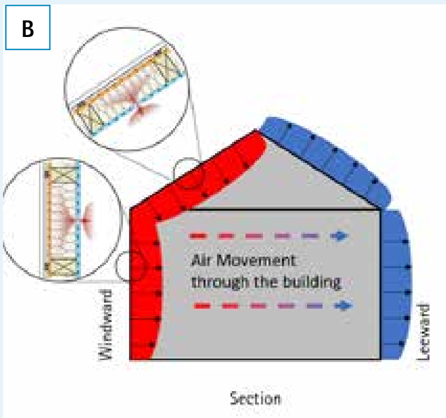


Figure 7.66 B: Wind pressure and wind suction on a freestanding building

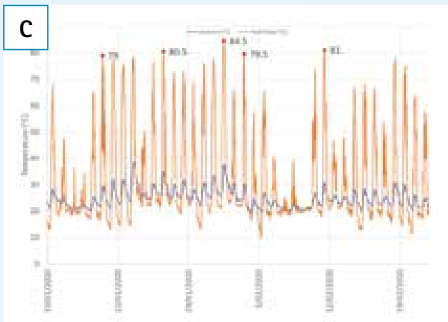


Figure 7.68: Roof Temperature measured in Sydney, January 2020 [111]. The blue line is the outdoor ambient temperature and the orange line is the roof surface temperature.

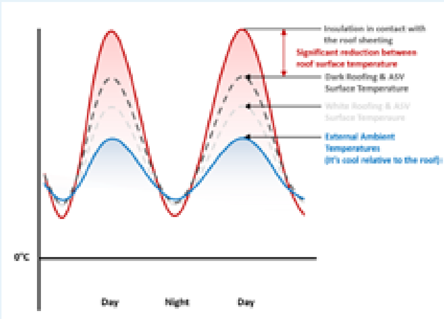


Figure 7.69: Roof surface daytime summer peak temperature reduction based on colour and ASV combination.

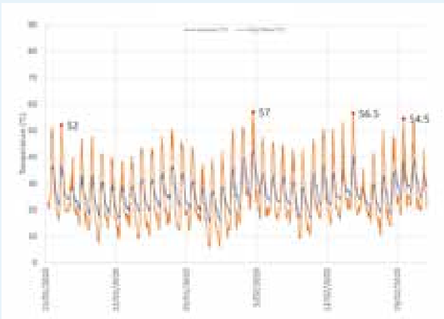


Figure 7.70: Roof Temperature measured in Perth, January 2020, [112]. Light coloured roof with ASV means the roof did not get hotter than 57 °C. The blue line is the outdoor ambient temperature, and the orange line is the roof surface temperature.

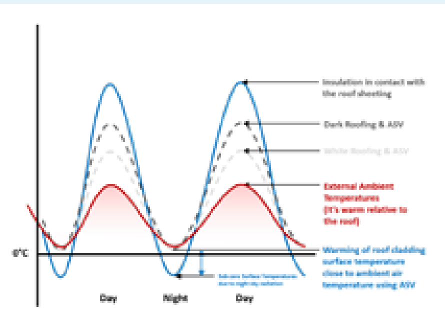


Figure 7.71: Representation of roof surface temperature winter minimum warming based on colour and ASV combination.

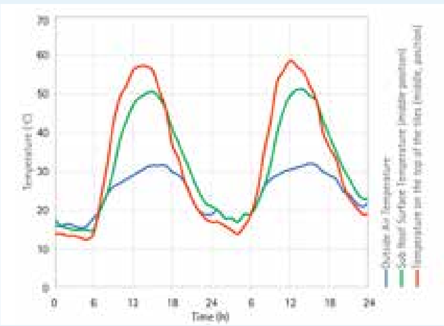


Figure 7.72: Surface temperature at the exterior surface of the roof cladding and on the sub-roof at the centre between eaves and ridge for a "normal"-ventilated, compared to the outside air temperature [92]. The sub roof temperature stays warmer than the roof cladding in the middle of the night due to the introduction of outdoor air.

7.5 R-value and thermal performance

Improving thermal performance is achieved by either increasing the system R-value or reducing the thermal gradient across the insulation layer or a combination of both. So, reducing the sub roof temperature in summer and increasing the sub roof temperature in winter is the key to getting the most out of your insulation. It is both the summer and winter extremes that the heat gains or heat losses are greatest.

Heat gains and heat losses can be managed by increasing R-Values. R-Value is the area of roof (m^2) that will result in 1 Watt heat transfer for 1 degree temperature difference (m^2K/W). An easier way to think of it is in heat transfer which is the amount of energy per square meter of roof for any given temperature differential (W/m^2K).

Taking a closer look at W/m^2K gives us a variety of ways to reduce the overall heat transfer in summer and winter. Traditionally the focus has been on reducing the energy transfer in Watts under a standard temperature differential across the system calculated in accordance with AS 4859.1 [113].

The AS 4859.1 conditions are:

- Summer: Outdoor 36 °C, Indoor, 24 °C, – Overall temperature differential is 12 °C
- Winter: Outdoor 12 °C, Indoor 18 °C – Overall temperature difference is 6 °C

Roofs can reach in excess of 90 °C in summer and sub-zero in the depths of night-time. Regardless of the climate region the key driver of peak temperatures is the daytime solar gain and the minimum is induced by night-time re-radiation of energy.

We need to take the focus off reducing the watts transfer but reducing the temperature difference across the insulation layer. This is when ventilation behind the cavity really changes the outcome. Here is why:

1) Roof temperatures with compress fibrous blanket were measured to consistently reach above 80 °C on an aged bare zincalume roof in Sydney in the summer of 2020. (Figure 7.68)

2) In summer the ventilation strategy can reduce the roof surface temperature and therefore the sub roof temperature by 25 – 30 °C. This reduces the driving force for heat down through the system and reduces the "work" the insulation needs to do. (Figure 7.69 & 7.70)

3) In winter, the ventilation below the cladding increases the roof temperature counteracting the night-time re-radiation of

energy to the night sky. The roof cladding and the sub roof are therefore closer to air temperature and can raise the temperature of the sub roof. This reduces the temperature difference across the insulation and therefore reduces the "work" it needs to do. (Figure 7.71 & 7.72)

7.6 Bushfire and burning embers

Controlling airborne embers of up to 2 mm in size is critical for protecting the roof space during bushfire events in accordance with AS 3959 (Figure 7.73, 7.74 & Table 7.2). It is considered that embers of less than 2 mm have insufficient energy to ignite building products within roof assemblies including membranes with a flammability index of less than 5. All pro clima membranes are fire retardant with flammability index of less than 5.
It is important that for ventilation opening calculation the open ratio is considered as some mesh types such as pinhole mesh can have as little as 25 % free open area. This means the total mesh area needs to be 4 times bigger than a completely unmeshed opening. The recommended opening area outlined in section 7.4.7 need to be considered in conjunction with options.

7.7 Pitched roof solutions

The ideal solution is dependent on climate, but any roof structure can be optimised to work in both summer and winter. It is recommended that any large air voids above insulation layers (trussed attics) are ventilated unless specialist advice has been sought for your building type and usage. Lighter roof colours are best for managing summer heat, but wintertime moisture related issue need to be considered. The risk of damage in "cool roof" solutions can be managed with INTELLO® PLUS Intelligent Air Barriers implemented at the ceiling line and allows these systems to be used across a much wider climate range with freedom from moisture damage.

7.7.1 Winter ASV solution

Remove moisture using a designed ventilation cavity. Counter intuitively the cold winter air entering the cavity at low level is warmer than the cladding which is exposed to night sky radiation. The ventilation therefore helps to warm the membrane reducing the risk of moisture damage and reducing the overall heat loss. The Above Sheathing (Membrane) Ventilation requires a Class 4 vapour

Figure 7.73: Bushfire Mesh designed into eave soffit to allow ventilation and prevent burning embers from entering as required by AS 3959 [114]

Figure 7.74: Behind Fascia ventilation grille being installed using perforated metal with 50 % open area [115]

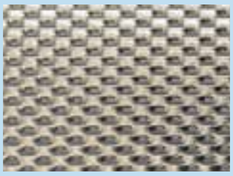
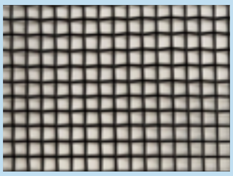
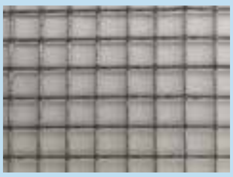
Mesh Type	Visual	% Open	Vermin	Bushfire
Pinhole Mesh		25 %	Yes	Yes
Pressed Mesh		41 %	Yes	Yes
Stainless Steel Bushfire Ember Mesh		75 %	Yes	Yes
Wire Mesh		85 %	Yes	No

Table 7.2: Mesh options to achieve protection from rodents and bushfire embers may restrict the airflow and need to be accounted for in the design of the inlet and outlet areas.

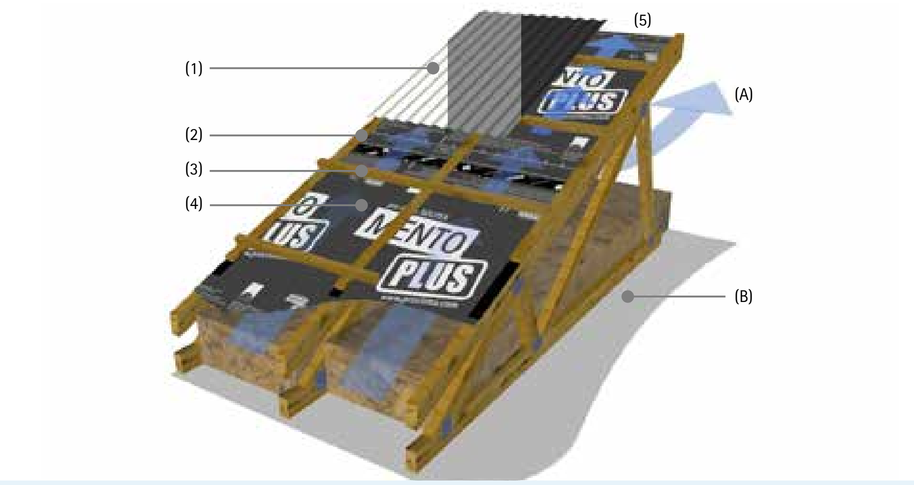


Figure 7.75: ASV provides optimum moisture management at the roof line. Ventilation of the attic is always recommended at a ratio of at least 1 m² of opening area for every 300 m² of insulated ceiling [116] [117]. Penetrations in the ceiling for down-lights, fans, smoke detectors, air diffusers and other features mounted in the ceiling lining provide air leakage pathways that carry less dense moisture laden air into the roof cavity.

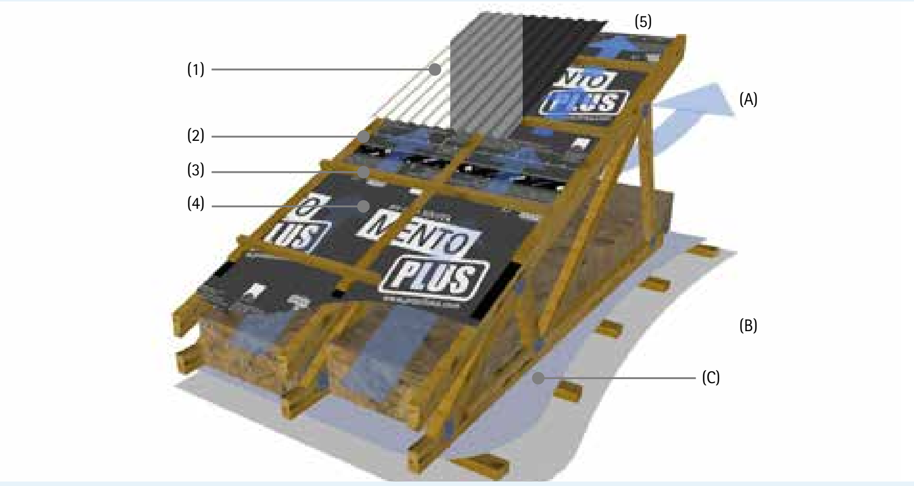


Figure 7.76: INTELLO® PLUS Intelligent Air Barrier system at the ceiling line coupled with a services cavity allows a continuous and undamaged vapour control layer which limits the upward movement of interior air into the roof space. This reduces the moisture entering the roof space assisting the ASV strategy to keep your roof dry. The large attic void should always be ventilated unless a specialist hygrothermal expert advises otherwise.

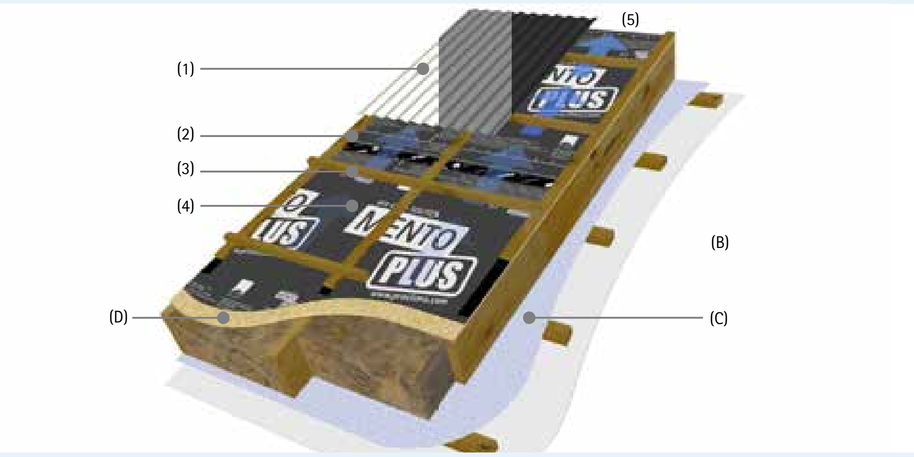


Figure 7.77: Removing the large air void inherent in truss roof design means the thermal and moisture characteristics of these roof systems are highly predictable. This means that with the right professional advice you can rest assured the roof will work as you intended (www.wufi.com.au/wufi-professionals). The membrane laid over a rigid board allow proper drainage at low slope roofs. Particularly useful for drainage below 10 degrees and ensures excellent drainage of the membrane during the construction process if it rains before the cladding is installed.

permeable membrane to allow the upward diffusion of moisture into the ventilated cavity where it can be safely expelled to outdoors. If INTELLO® PLUS is used at ceiling level a class 3 or 4 membrane is suitable. The large attic void should always be ventilated with a ratio of 1 m² of ventilation for every 300 m² of ceiling area, unless a specialist hygrothermal expert advises otherwise. Low slope roofs are riskier, and the building code of Australia requires the ratio to be increased to 1/150 for roof pitches below 22 °C. Inlet vents should be dimensioned slightly larger than the outlets to ensure all makeup air comes from outside and is not drawn from inside the building. (Figure 7.75 & 7.76).

7.7.2 Winter super solutions

Optimum winter performance for both skillion and trussed roofs requires structured ventilation between the cladding and the WRB enabling moisture to be removed from the external side, and an IAB to prevent wetting from the inside. (Figure 7.76 & 7.77) INTELLO® PLUS reduces the moisture load added to the truss roof space or rafter space perfectly complimenting the Above Sheathing (Membrane) Ventilation strategy for optimum moisture control.

7.7.3 Summer ASV

Structured ventilation strategies require specific addition of ventilation behind the cladding and within any large air voids (attic/roof space) above the insulation layer. This formulates the basis of super strategies to remove heat at cladding level and from within any un-controllable large air voids within the roof structure (Figure 7.78).

Legend:
(1) Roof sheeting (light, medium, dark)
(2) Counter batten
(3) Fixing batten
(4) SOLITEX MENTO®
(5) Above Membrane Ventilation
(A) Attic ventilation (Opening ratio 1:300)
(B) Plasterboard ceiling (with leakage penetrations)
(C) INTELLO® PLUS
(D) Rigid sheathing (bracing)

7.7.4 Summer super solutions

Optimum summer performance is achieved with light roof cladding to reduce the amount of solar heat absorbed combined with removal of heat using convection in the ASV structured ventilation strategy.
Light coloured roofs keep the WRB cooler in summer reducing the work the insulation needs to do reducing the heat flow down. However, in winter the roof is also colder and this increases the risk of moisture related problems behind the WRB, therefore INTELLO® PLUS is required to protect from excessive internal moisture and the system works in both seasons across a wider range of cool temperate climate zones with lighter coloured roofs (Figure 7.79 & 7.80).
The summer super solution works best with INTELLO® PLUS to prevent warm/hot air from the outside of the insulation flowing unhindered through the insulation to the inside. This helps prevent uncontrolled heating of the interior and overheated rooms, excessive energy consumption and excessive energy costs.

7.7.5 Design requirements

Structured ventilation strategies require specific addition of ventilation behind the cladding and within any large air voids (attic / roof / truss space) above the insulation layer. This formulates the basis of super strategies to remove heat and moisture at the cladding level and from within any uncontrollable large air voids in the roof structure (Figure 7.78 & 7.79).

Legend:
(1) Roof sheeting (light, medium, dark)
(2) Counter batten
(3) Fixing batten
(4) SOLITEX MENTO®
(5) Above Membrane Ventilation
(A) Attic ventilation (Opening ratio 1:300)
(B) Plasterboard ceiling (with leakage penetrations)
(C) INTELLO® PLUS
(D) Rigid sheathing (bracing)

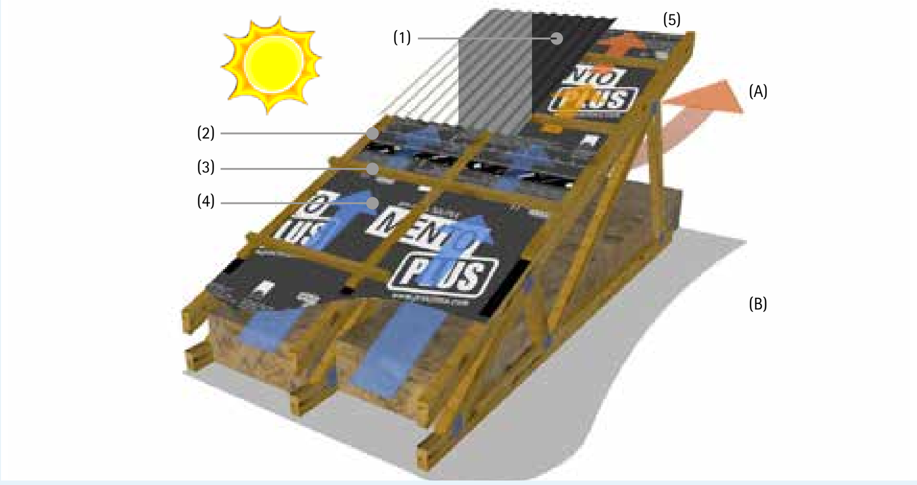


Figure 7.78: Remove heat using a designed ventilation cavity under the cladding. Cooler air entering the cavity at low level absorbs heat from the cladding as it rises to the ridge or high point. The ventilation therefore helps to cool the membrane reducing the overall heat flow downward into the living space. The large attic void should always be ventilated with a ratio of 1 m² of ventilation for every 300 m² of ceiling area or 1 m² for every 150 m² of ceiling when the roof pitches below 22° [117].

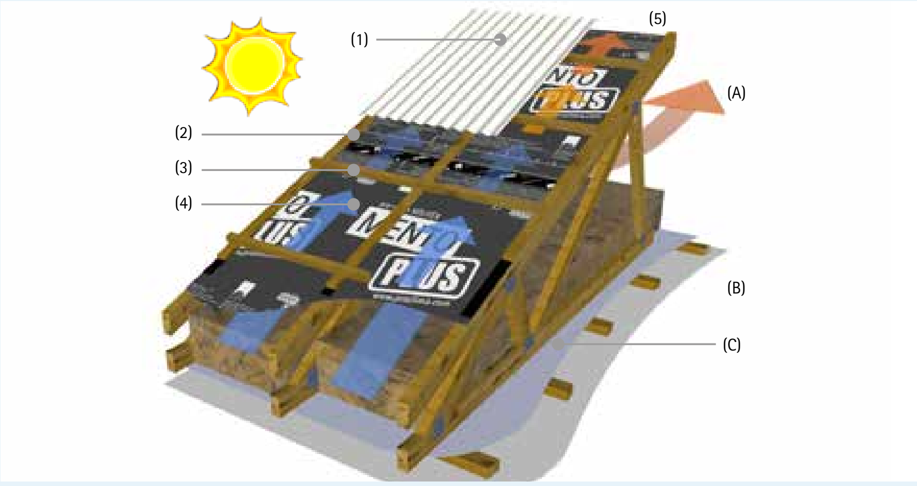


Figure 7.79: INTELLO® PLUS Intelligent Air Barrier system at the ceiling line coupled with a services cavity allows a continuous an undamaged vapour control layer which limits the upward movement of interior air into the roof space. This means cooler coloured roofing systems can be used for enhanced summer performance in mild to cool temperate climates without any unintended winter condensation damage. This should be verified by qualified engineer based on local climate conditions.

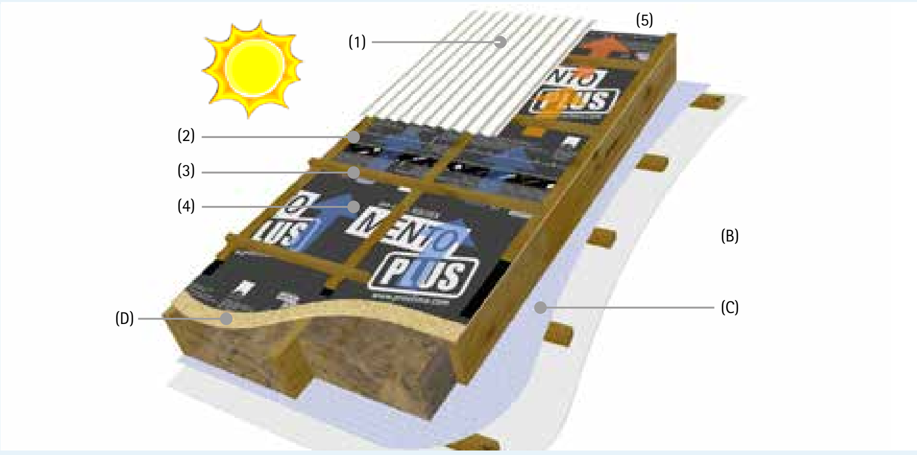


Figure 7.80: Removing the large air void inherent in truss roof design means the thermal and moisture characteristics of these roof systems are highly predictable. This means that with the right professional advice you can rest assured your roof will work as you intended in summer and winter in any climate zone. Roof slope should be limited to 5 degrees with the SOLITEX MENTO® system to facilitate drainage. Ask a professional for verification www.wufi.com.au/wufi-professionals.

7.7.5.1 Design requirements – structured ASV

It is recommended only "normal" or "strong" ventilation strategies are employed for the cavity between the cladding and the WRB.
The design thresholds are:

- Normal Ventilation is achieved with nominal 20 mm high counter battens. This achieves approximately 200 cm² of roof cross sectional open area per lineal metre.
- Strong Ventilation is achieved with nominal 45 mm high counter battens (≥40 mm). This achieves approximately 400 cm² of roof cross sectional open area per lineal metre.
- The eave free open area should be no less than the roof cross sectional open area, including any adjustments for vermin or bush fire mesh.
- The ratio for the structured ASV ventilation opening sizes should be minimum 1:4, where the ridge vent area is at minimum ¼ of the calculated eave vent area.

7.7.5.2 Roof form adjustments

Where the resulting ridge length is less than the eave length (e.g. hip roof) due to geometry, the eave inlet size should be calculated based on total eave length and the outlet at the ridge distributed evenly along the ridges with a vent opening area of ¼ of the total eave inlet area. This means ridge vents may need to be enlarged compared to a basic gable or mono-pitch roof.
On the sections of a roof where there is no ridge parallel to the eave to fit an outlet (e.g. any type of hip roof), then an additional vent would need to be added.
Where the ridge is venting two ASV roof sections on either side (e.g. standard gable), then the ridge capping vent area needs to allow for the total openable area for both sides.

7.7.5.3 Design requirements – ventilated roof spaces

pro clima recommends that large air voids on the outside of insulation layers (e.g. truss spaces) are ventilated, unless specialist hygrothermal design advice has been sought.
Recommended total open vent area including eave inlets and ridge outlets should be equal to the 1:300 ratio between the net free opening area of the vents to the area of insulated ceiling.

- Approximately 30 % of the total unobstructed vent area required should be located not more than 900 mm below the ridge or highest point of the roof space, measured vertically.
- The remaining 70 % of required opening area should be provided by the eave vents.
- Dimensioning inlet vents larger than the outlets ensure all makeup air comes from the outside and is not drawn from the inside.
- The outlets for the ridges will be based on the greater of:
  - The ridge ventilation requirement for the structured ASV ventilation pathway behind the cladding, or
  - The requirement for the ventilation of the attic based on 30 % of the 1:300 ceiling ratio ensuring the ridge capping detailing allows for the required open area.

Eave vents should be evenly distributed around the roof perimeter.
Outlet vents, such as ridge vents, must only be installed in conjunction with inlet vents.

7.7.5.4 Design requirements – mesh

In Australia, cavity closers must meet AS 3959 requirements for bushfire protection up to BAL 40 (Standards Australia, 2018). This can be achieved by fitting an ember guard made of non-combustible material, or a mesh or perforated sheet with ≤ 2 mm holes made of corrosion-resistant steel or bronze.

7.7.5.5 Design requirement – cool roofs

The addition of an IAB and vapour control layer at the ceiling level, adds further protection by limiting the pathway for warm, humid air to enter the roof assembly in winter (Figure 7.79).
Cooler coloured roofing systems can be used for enhanced summer performance in mild to cool temperate climates using pro clima INTELLO® PLUS to manage winter condensation risk. The roof assembly can be super enhanced by removing the large void altogether, as is the case with a skillion or cathedral roof (Figure 7.80) using the structured ASV design requirements. This provides the most predictable outcome for beating moisture and heat.

7.8 Flat roofs

It is often said that there are two types of flat roofs: leaky flat roofs and not yet leaky flat roofs. Low slope roofs are at high risk of water leaks, and if they do not leak at the outset then they are likely to start leaking after several years of operation. Of primary concern is the waterproofing, which is best achieved on low slope roofs using a fully chemically welded, torched on or liquid applied membrane which fully seals the roof structure. These are typically of high vapour resistance and prevent outward diffusion of water vapour. When placed on the cold side of the construction can lead to severe issues. If the membrane is exposed directly to the outside air, in the worst case directly facing the sky, then the membrane is subject to night sky radiation and large diurnal swing. This puts stress on the membrane from daytime expansion and nighttime contraction. This is worst when the insulation is placed entirely below the rigid sheathing on which the membrane was applied. (Figure 7.81) The exterior weatherproofing membranes should be protected from large temperature cycling using an insulation layer above the membrane. In the ideal solution all insulation is situated above the weatherproofing membrane. Of particular importance are:

- **Roof colour:**
  Light coloured coating on the upper surface reduces the annual average operating temperature of the roof. In winter this means the outer layers have a higher risk of moisture accumulation. Dark coloured roofs absorb more heat that drive moisture away from the outer layers of the construction.
- **Location of the insulation:**
  At least some of the insulation but preferably all of it should be placed on the outside of the water and vapour impermeable membrane. The ratio at which the insulation is split between the external side and internal side defines the surface temperature at the rigid board which is covered by the impermeable water and vapour barrier. Moisture will collect in this board if too much insulation is placed below the board.
- **Vapour control layers:**
  If any of the insulation is placed below the water and vapour impermeable membrane, then an IAB is required for vapour control on the in side of the main structure. (Figure 7.82 & 7.83)

"Tiled decks over habitable rooms are one of the most high-risk constructions, in my opinion. Failure of waterproofing / tiling systems on decks is a big enough issue itself. Additionally, moisture management below the deck is often overlooked in their design and construction. Failure to duct bathroom fans etc. below the deck to the atmosphere is one way to compromise an otherwise well-built system. This unfortunate example has a bathroom and laundry below, with fans which discharge straight into the enclosed joist space below the deck. This appears to have caused swelling of the joists beside the fan discharge bay, resulting in pooling of the water on the deck. Many reputable waterproof deck membranes are not designed for immersion. With prolonged immersion they will re-emulsify and eventually fail (leak). A very ugly and expensive mess. The location of the bathroom fan is directly below the purple tape measure (with the tape sticking up-far corner). This lines up perfectly with the hump in the deck. Owners have applied membrane over tiles to try to minimise water entry until repairs are done."
Macalister, Iconic Construction [118]

Figure 7.81: Damage to a flat roof construction due to poor waterproofing and internal water vapour management [118]

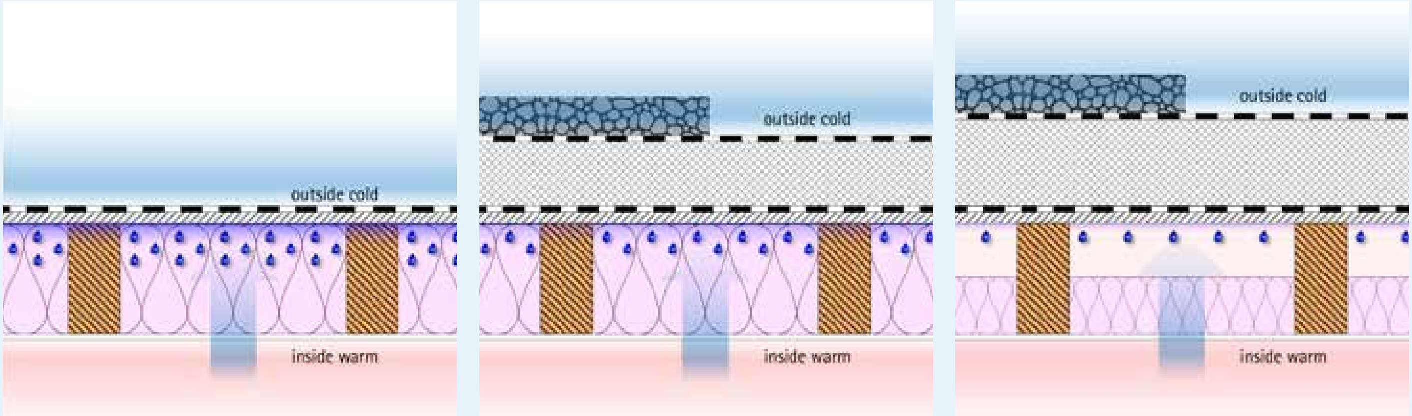
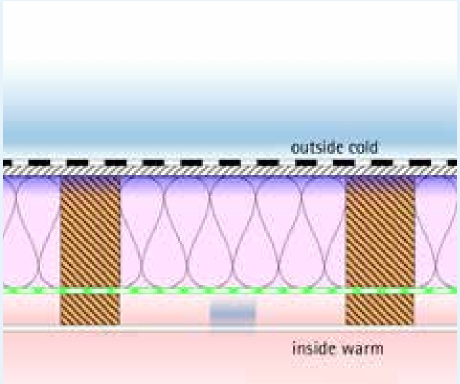
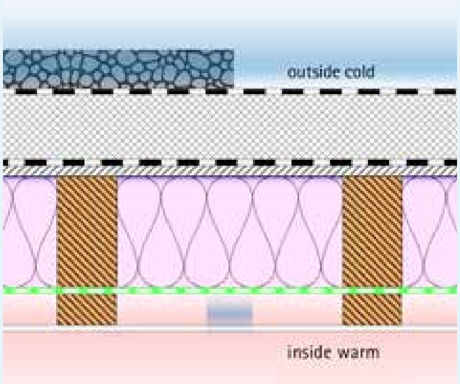


Figure 7.82: Non vapour controlled flat roof assemblies. Balancing the amount of insulation above and below the rigid roof sheathing is important. Insulation placed below the rigid board triggers the possible need for a vapour control membrane. This needs to be assessed by a WUFI® professional (www.wufi.com.au/wufi-professionals). These constructions have a high risk of condensation and thereby following of mould, mildew and decay. Not being recommended besides climate zone. Further to the moisture added by diffusion there is a moisture added by convection, which can create a compounding effect and more additional water than planned. 1. **Left:** All insulation is placed below the rigid board and weatherproofing layer. A fully sealed waterproof membrane (water and vapour barrier) above the insulation layer. This is high risk of moisture accumulation in the rigid board. **Middle:** Some insulation is placed below, and some is placed above the rigid board. A dual weatherproofing layer on top protects the outboard insulation layer with a fully sealed waterproof membrane (water and vapour barrier) above and below the insulation layer. There is still a risk of moisture accumulation in the rigid board, but this is climate dependent and based on key design parameters such as roof colour. **Right:** Reducing the amount of insulation below the board relative to above the board results in a reduction in the risk of condensation and moisture accumulation in the board.





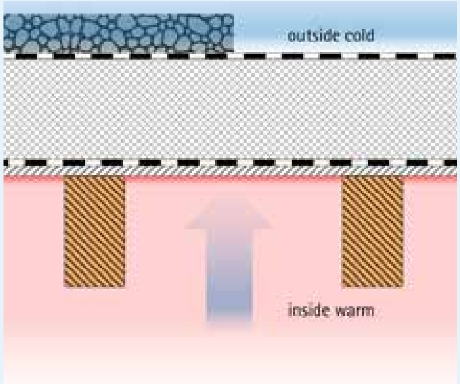


Figure 7.83: Vapour controlled flat roof assemblies. If insulation is placed below the rigid sheathing material, then a vapour control membrane assists in the moisture management. Roof colour, climate and insulation split above and below will define the hygrothermal safety of the roof. This needs to be assessed by a WUFI® professional (www.wufi.com.au/wufi-professionals). Perfect airtightness is essential in this construction, therefore it is recommended to assess the tightness using a Blower Door test - see chapter 8. **Left:** INTELLO® PLUS Intelligent Air Barrier provides vapour control to prevent water vapour migration to the external "cold" board. This significantly increase the durability of this system, but the outcome is dependent on the climate and key design parameters such as roof colour and moisture management of the internal conditions with controlled mechanical ventilation strategies. **Middle:** An internal Intelligent Air Barrier provides vapour control to prevent water vapour migration to the external "cold" board. This significantly increase the durability of this system but is dependent on the climate and key design parameters such as roof colour and moisture management of the internal conditions with controlled mechanical ventilation strategies. **Right:** Completely removing the insulation from the structure removes risk of condensation. This is a "warm roof". construction [rafters, perlins, beams] are in warm situation.

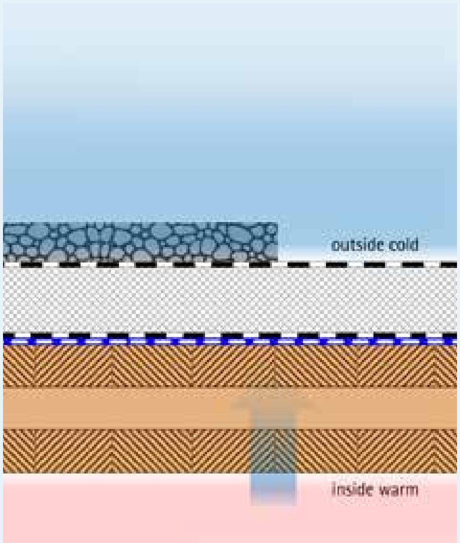
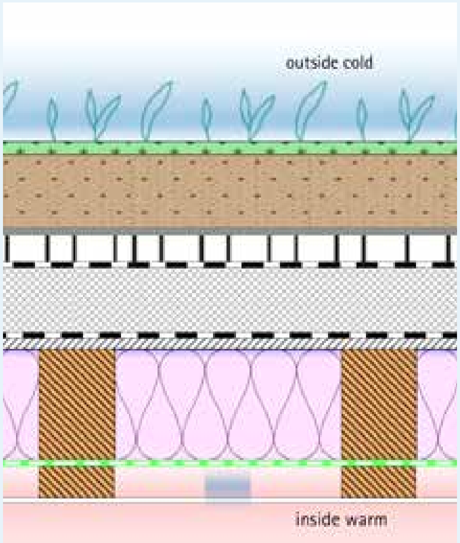


Figure 7.84: Low slope Cross Laminated Timber (CLT) roofing solution. Systems incorporating mass timber which acts as a hygric buffer to store and release moisture allows a high level of hygrothermal safety and therefore no IAB is required. Mass structures are best over insulated as the mass timber is kept warm and dry. This lowers the moisture content and removes the risk of mould and decay. SOLITEX ADHERO® is used for temporary rain protection during construction to ensure the CLT remains dry from the outset. The SOLITEX ADHERO® will have no impact on the overall operation of the assembly and is only intended for the construction phase when a vapour barrier will be installed over.



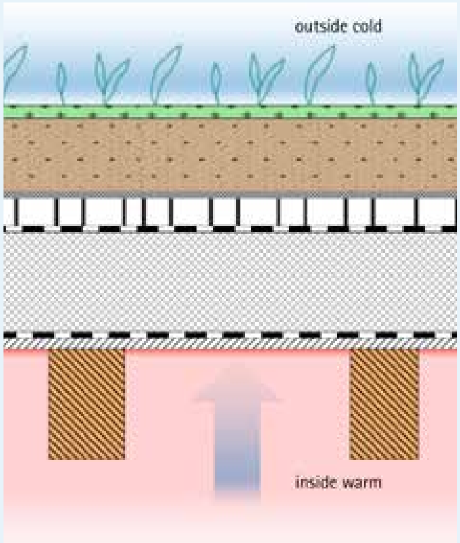
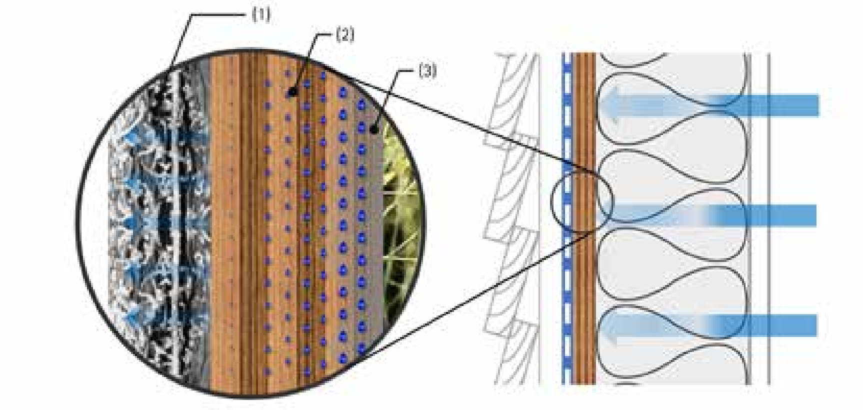


Figure 7.85: Green roofs assemblies are special cases in which it is essential to get professional advice on the moisture balance to manage the poten-tial for damage (www.wufi.com.au/wufi-professionals). The safest option is to place all insulation above the rigid roof sheathing. **Left:** In warm and moderate climates (BCA Climate 1-5) it may be possible to split the insulation with some below and some above the rigid board. INTELLO® PLUS Intelligent Air Barrier prevents the upward movement of humid air and reduce the risk of damage. **Right:** In colder Australian climates (BCA Climate 6-8) all insulation may be placed above the rigid board. A fully sealed waterproof membrane (water and vapour barrier) above and below the insulation layer. This keeps the internal surface warm.

7.9 Summary

- Healthy buildings require internal lining surface temperature to be maintained above critical levels to ensure high surface humidity does not cause mould.
- Continuous insulation is required in the building code, and this means ensuring continuity across the entire ceiling. This may require modification to truss design and wall/ceiling junctions to accommodate insulation thicknesses required.
- The ideal roof structure has the same components as a wall system, vapour permeable Weather Resistive Barrier (WRB), Intelligent Air Barrier (IAB) on the inside and a ventilated cavity behind the cladding.
- A drained and ventilated wall cavity is used to remove water, condensate and evaporate moisture. In summer, the ventilated cavity removes heat by convection. This wall assembly on its side forms the ideal roof configuration. A drained and ventilated roof assembly works in the same way.
- When membranes are hard up against the cladding problems start to occur when temperature cycling and wetting/drying cycles are repeated day in, day out. The underlay material is exposed to some extraordinary conditions.
- It is necessary to use membranes with high durability such as TEEE technology used in the pro clima SOLITEX product range which has over 100 °C continuous operating temperature, up to 180 days UV exposure and outstanding resistance to wet and dry delamination.
- Membranes which laminate metal surfaces to polymers will have differing co-efficient of expansion leading to early deterioration.
- Above Sheathing Ventilation (ASV) is a strategy which employs a ventilated air layer between a vapour permeable membrane and the roof cladding to remove moisture in winter and heat in summer.
- Roofing membranes provide a secondary line of defence from defects in tile or metal cladding as well as workmanship or detailing errors and extreme driving rain events.
- Counter battens are a vertical set of battens laid over the membrane aligning to the trusses or rafters and used to create a structured ventilation pathway in ASV solutions.
- Water vapour can and will pass through any unsealed ceiling penetrations. Even if they are sealed water vapour diffusion can carry water vapour through the ceiling. INTELLO® PLUS as a dedicated IAB at the ceiling line removes the risk of unnecessary water vapour entering the rafter structure of truss attic.
- Structured ventilation behind the cladding warms the sub-roof in winter countering the effects of night sky radiation. This reduces the heat loss from the system.
- In the tropics it may be necessary to have a well-sealed vapour control layer over the roof structure and continuous with the wall membrane to prevent mould on the interior plasterboard. Details are subject to climate, conditioning strategy and building type.
- ASV is a year round roofing solution. During the coldest depths of winter nights, air movement between roofing cladding and the membrane will help reduce or even eliminate condensation from the underside of roofing material. Any condensation that does form can be freely drained away via the clear pathways created between counter battens.
- Harsh summer conditions expose roofs to severe solar radiation. This can add significant and uncomfortable heat loads to our buildings. The air movement induced by ASV helps to alleviate this problem, no matter the cladding type or material colour.
- If no IAB is present at the ceiling line it may be necessary to ventilate a truss attic space. (Excl. NCC Climate Zone 1)
- If there is an IAB at the ceiling line it may be possible to seal the truss attic subject to professional advice based on climate, conditioning strategy, and building type. (Excl. NCC Climate Zone 1)
- The Above Sheathing (Membrane) Ventilation requires a Class 4 vapour permeable membrane to allow the upward diffusion of moisture into the ventilated cavity where it can be safely expelled to outdoors. If INTELLO® PLUS is used at ceiling level a class 3 or 4 membrane is suitable.
- If a rigid roof sheathing is used to support the WRB, INTELLO® PLUS is recommended in all climate zones (Excl. NCC climate zone 1)
- INTELLO® PLUS will always reduce the risk of interior water vapour entering rafter bays or truss attic and creating humidity related issues.
- Roof structures should always be built to be as vapour permeable as possible to allow any construction moisture to dry out as quickly as possible.
- Summer heat can be managed by ASV strategy and is one of the most effective summer heat management strategies. It employs the age-old architectural parasol roof concept on a small scale.
- Light coloured roofs are an effective strategy for reflecting heat and compliments ASV for optimum summer performance. This can reduce the heat flow down by 70%. It is recommended that INTELLO® PLUS IAB is used to ensure the light-coloured roof does not cause winter-time moisture issues with cool roof solutions.
- Reflective roof solutions can become dull over time reducing in performance, ventilation under the roof cladding ensure heat is always removed.
- ASV is self-regulating, this is when darker coloured roofs drive more convective heat removal. This means the negative summer effect of darker coloured roofs is not as extreme as expected when employing an ASV strategy.
- Minimum counter batten heights should be 20 mm but taller is preferable for better summer heat removal. Eaves should employ a minimum of 200 cm^2/m opening area and the ridge a minimum of 50 cm^2/m. Any mesh for bushfire or vermin should be accounted for using the openable area ratio.
- For flat roof solutions, all insulation may be placed above the rigid substrate.
- The main advantage of flat roofs based on a timber frame construction is that it provides a very efficient use of space because the insulation can be installed above and between the structural elements which allows slim constructions.
- Slim constructions are particularly useful for gaining approvals in height restricted zoning. When compared to SOLID constructions with concrete or mass timber roofs where insulation adds thickness.
- If any insulation is placed between the rafters, it is necessary to include INTELLO® PLUS IAB below the insulated structure to reduce the risk of moisture damage due to condensation.

A



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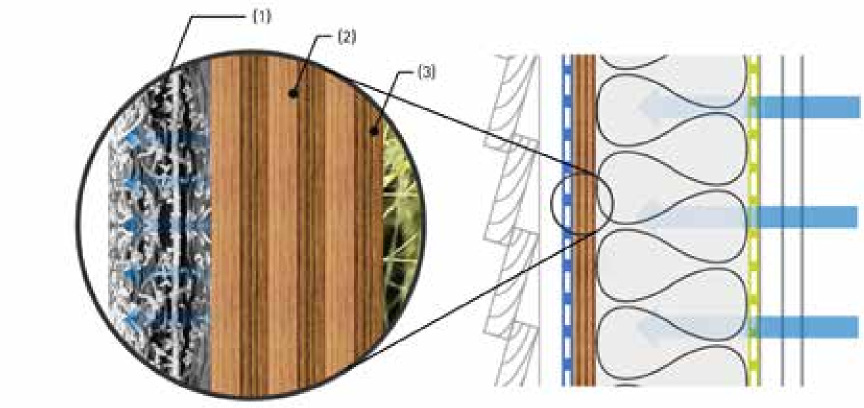


Figure 8.1: Building Envelope Science – Mould Index (A) Exterior airtightness can be created with adhesive membranes over rigid boards but this increases the risk of high humidity and mould growth on outer layers. Expected MI > 2 in climate zones 2-8, where colder climates present even more risk MI > 3. (1) Class 4 vapour permeable; (2) Moisture in sheathing; (3) Mould (B) Interior airtightness allows for optimal vapour control and keeps the outer layers dry and mould growth at or near MI = 0. (1) Class 4 vapour permeable; (2) Dry sheathing; (3) No mould

8. Quality assurance of airtightness

In previous chapters, physical effects of air entering the structure from the warm side have been described. Penetrating air reduces the energy efficiency by losing warm air from inside the building to the outside (climate zones 2 to 8) or by warming up the inside from the outside (climate zone 1). Penetrating air may increase the humidity in the construction, resulting in condensation. This may lead to mould on surfaces and within building materials. Mould is a precursor for decay but also for ill-health. A well-sealed Intelligent Air Barrier (IAB) membrane on the warm side of the thermal insulation construction – in climate zones 2–8 on the inside, in climate zone 1 higher vapour resistance Weather Resistive Barrier (WRB) layers on the outside of the thermal insulation – prevents infiltration of moisture laden air.

In addition to protection against moisture ingress through vapour diffusion, the humidity-variable diffusion resistance simultaneously offers a high drying potential.

The calculations with WUFI® Pro (Chapter 6.0) show with INTELLO® PLUS the lowest humidification with lowest Mould Index (traffic light: green) for the construction, i.e. the highest protection against mould and decay for the building materials and optimal health of the occupants or users of the buildings. (Figures 8.1).

For airtightness to be effective three things need to be considered:

- 1. Planning (detailed plans need to be developed)
- 2. Execution (installation of the air barrier)
- 3. Verification (testing of the air barrier / Blower Door)

If one of the three steps above is missed, the outcome will not be satisfactory.

8.1 Quality Control of airtightness – design stage

8.1.1 Air barriers – products, assemblies, and systems

Some key terms are useful for discussion about airtightness and how to achieve good outcomes:

- **Air barrier material** – an impermeable material that retards air movement, such as a membrane or SOLID concrete.

- **Air barrier assembly** – air barrier materials joined by sealing accessories into a continuous impermeable layer, such as a wall or roof.
- **Air barrier system** – the collection of air barrier assemblies joined by air barrier accessories and components into a continuous barrier to air movement, building-wide.

One key consideration is that parts of the building not seemingly related to the air barrier assemblies – mechanical, electrical, and plumbing systems, for example – may become significant pathways for air leakage when the building is in operation. That is why it is essential to think of a building as a system of interactive parts.

INTELLO® PLUS is an air barrier material when sealed at overlaps and end laps with TESCON® VANA forms an "air barrier assembly" for ceilings and walls. When it is then connected into built-in components such as windows and door jambs using ORCON® CLASSIC, TESCON® and/or CONTEGA® products as well as sealed around pipe and cable penetrations (KAFLEX/ROFLEX) a complete "air barrier system" is formed. The use on site and the serviceability is higher if the acrylate adhesive of the adhesive tapes and the air sealing connection adhesive are water-resistant, as is the case with the adhesives from pro clima with (SOLID glue). This is the systems design thinking required for superior outcomes.

8.1.2 Planning

Basic steps for continuity of an air barrier are required on any project.

To achieve a more airtight building, it is advisable to start the effort early in the project design. Improvements identified at this stage will cost a fraction of remedies in the future. A practice as simple as the Red Pen Test (Figure 8.2) will aid a project team in identifying challenging junctions and transitions.

8.1.3 Verification

An important aspect for the high quality of a service is Quality Control (QC). This detects and eliminates errors and teaches you how to avoid these errors in the next orders. In industrial manufacturing, QC is indispensable. The entire manufacturing process is validated several times, from the product – the intermediate products to the final products – as well as from the manufacturing process – e.g. via the ISO 9000 leading processes. If QC does not work properly, the risk of defects is high and the damage can be considerable, as we hear about car or food recalls in the media.

Quality Control in construction is usually higher in the industrial construction process (creation via prefabrication) than in the site build process (creation on site), but in the site build construction process as well, QC is in some areas state of the art, e.g. at the installation of water pipes in a building. No plumber would allow that the installation of water supply pipes to be covered by the internal linings, such as plasterboard, without having filled the pipes with water and checked that all connections are really completely watertight, e.g. if the skin of the hand stays dry if touched. For more complex water supply systems, one can do a QC via a pressure test. A pressure gauge is installed, and water pressure is applied to the pipe system. Further water supply is stopped. The pressure gauge shows regular pressure. After a few hours on test, leaks can be shown by a drop in pressure. If the pressure is reduced, one knows that there is a leak somewhere. The plumber searches for any leakages Until they find and fix them, knowing that otherwise the construction will get wet and mouldy around the leakage. Although buildings aren't required to operate at such extreme pressures and therefore have lower sealing requirements than water pipe tests. Buildings should still stay below specified air leakage limits that take into account in real buildings perfection is not possible.

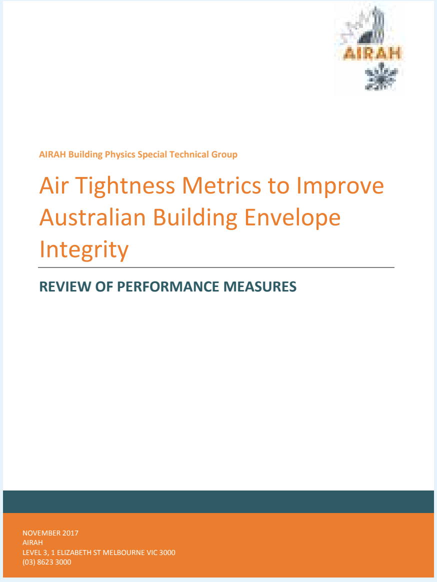
Using a similar idea a requirement could/should apply to air sealing buildings, which plays a large part in keeping the building durable and energy efficient. The QC refers to the air sealing as an entire system and here, too, a pressure test can be carried out to check for airtightness leakages.

The quality control of air sealing is carried out by the so-called differential pressure method. An air pressure difference is built up inside the building to the outside with a fan that is installed in a door for testing. Either the fan pulls air out of the building, creating a negative pressure (a mini-vacuum), or the fan pushes air into the building, creating a positive pressure (a mini-inflation). Air leaks out at the leaking points can either be sensed sensitively with the skin (e.g. the back of the hand) or made visible visually (e.g. with effect-fog from a fog generator, Figure 8.3). The differential pressure used is on average 50 Pa, which corresponds to a wind force of 5–6 Beaufort (approx. 33 km/h) and 50 N/m².

Simply described, it is a blower fan mounted

Figure 8.2: Red Pen Test

Figure 8.3: Using smoke bottle diagnostic tool to check for air leaks during Blower Door testing. Photo courtesy of Michael Limb Builders


AIRAH

AIRAH Building Physics Special Technical Group

Air Tightness Metrics to Improve Australian Building Envelope Integrity

REVIEW OF PERFORMANCE MEASURES

NOVEMBER 2017
AIRAH
LEVEL 3, 1 ELIZABETH ST MELBOURNE VIC 3000
(03) 8623 3000

Figure 8.4: AIRAH guideline [119]

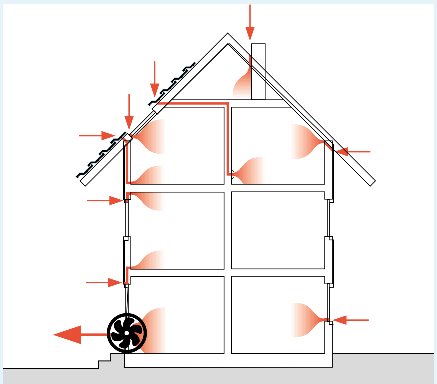


Figure 8.5: Schematic diagramm of an airtightness test


Figure 8.6: Blower Door test

in a temporary door - hence the common name of "Blower Door" for the tool.

Quality control of airtightness – the Blower Door test during construction:
The best way to ensure the correct and effective application of airtight vapour control layers is to use a Blower Door once the air barrier system is complete, but the internal linings have not been installed. This allows for rectification and correction of issues found using Blower Door pressurization. The more airtight the INTELLO® PLUS Intelligent Air Barrier (IAB) system the more effectively it works.

It's essential to check the connections and the joints, not the surfaces, just as it is important to check the connections and not the pipes in a water supply installation. Leaks can be detected sensitively via the skin, usually with the back of the hand, similar to the water installation, here whether the palm of the hand and the fingers remain dry. Other ways of detecting leaks are effect-fogs from hand fog generation pumps or delicate paper strips. In Climate Zone 2 - 8, leaks are searched for in the building with a negative pressure. In Climate Zone 1, the air seal is on the outside. Here, the most effective way to test is to fill the building completely with effect-fog and do an overpressure test - the fog can be seen blown out at the leaks.

During the test, the leaks can be sealed to increase the airtightness of the building envelope and re-tested.

Quality control of airtightness – the Blower Door final test:
After completion of the building, the final determination of the quality of the airtightness takes place. Both the negative pressure method (mini-vacuum) and the positive pressure method (mini-inflation) are used. The volume of air that must be sucked out of the building or blown into the building to achieve a differential pressure of 50 Pa in the building compared to outside is determined. If there are many leaks, the volume of air required to achieve the mini-vacuum or mini-inflation is greater; if there are few leaks, the required air flow volume is lower.

8.1.4 Airtightness metrics

Permeability vs. Air Changes per Hour (ACH): The metric commonly cited in Australian regulatory language is air permeability. This is simply the rate of air leakage divided by the surface area of the building envelope. The resulting metric, airflow at 50 Pascals pressure and normalised by surface area (qE_{50}) is widely used by standards worldwide to compare results. It is the metric cited by the 2019 National Construction Code (V2.6.2.3).

$$qE_{50} = \frac{\text{air leakage at 50 Pascals}}{\text{building envelope surface area}}$$

Lower permeability means less air leakage and usually lower energy costs and more protection against mould and decay.

Results are also reported as ACH at 50 Pascals (n_{50}), which is simply the rate of air leakage at 50 Pascals divided by the building volume. qE_{50} and n_{50} are very similar metrics for common homes.

$$n_{50} = \frac{\text{air leakage at 50 Pascals}}{\text{building envelope volume}}$$

The reason that qE_{50} and n_{50} yield similar results for houses is that, for houses, the volume in m³ and the surface area in m² is very similar. On average, in fact, a study of Australian home airtightness test results found almost an exact 1:1 ratio of average house volume and average house surface area (Figure 8.4. "Airtightness Metrics to Improve Australian Building Envelope Integrity", 2017). That is why for discussion purposes, qE_{50} and n_{50} are practically interchangeable in conversation about detached homes.

For larger buildings, volume is often much larger than surface area. For example, a Blower Door test of a small school may result in 20,000 m³/h of leakage measured. This is then divided by the volume of the school (9,600 m³) and the surface area (3,040 m²). As a result, the n_{50} is 2.08 1/h while the permeability is 6.58 m³/(h·m²). There is more than three times as much leakage per unit of surface area than per unit of volume. In effect, for larger buildings, much more leakage allowed when using a volume-based metric. Because building sealing is always accomplished using air barrier materials, it makes sense to use a surface-area based metric such as qE_{50} permeability. The cost, time, complexity, and difficulty of sealing is only related to the amount of surface area that must be sealed, and the volume enclosed by that surface area is irrelevant. That is why many countries and standards are now favouring metrics such as qE_{50}, because they more evenly appropriate for all building types regardless of size.

To determine the n_{50} or qE_{50} value, a computerized test guide is used to take hundreds of readings to determine the air flow rate at different pressure differences, incl. the standard deviation, etc. The final value is the average of two test procedures: a negative (sucking) and positive (blowing) pressure test result. (Figure 8.5 – 8.6)

8.2 Quality Control of airtightness – failings of energy regulations

The National Construction Code for years has included language meant to address the problem of air leakage. In Volume 2, Section 3.12.3 Building Sealing outlines several items that must be addressed. Unfortunately, the language is woefully ineffective and unenforceable. For example: "A roof light must be sealed, or capable of being sealed, when serving a conditioned space..." [120] (Figure 8.7)

Language of this ambiguity does not lend itself to consistent enforcement. Compliance would require a subjective opinion of a code official, one that may vary from person to person. There is no quantitative target that can be verified or compared.

To address this problem, the NCC 2019 also includes an option to use a Blower Door measurement (AS/NZS ISO 9972:2015) [121] to verify compliance with a requirement to seal the building envelope against air leakage. In section V2.6.2.3 to demonstrate compliance, the test must show that a permeability of 10 $m^3/(h \cdot m^2)$ at 50 Pascals or less has been achieved.

This target of 10 $m^3/(h \cdot m^2)$ at 50 Pascals is not a difficult target and may yet leave many problems unaddressed, but the option in the code for a quantitative, not subjective, assessment of compliance is important to lay the groundwork for stronger code language. A n_{50} or qE_{50} of 10 means that if all leakages are added together, it would be like leaving a window in a house permanently half open. This is not a satisfying situation neither for energy savings nor for protection against mould and decay.

A common saying applies: "If you can't measure it, you can't manage it." This will be the first step of many more to come.

8.2.1 Airtightness testing standards

There are a number of international standards detailing almost identical procedures of testing for airtightness, all involving repeated airflow measurements over a range of pressures. Data from the test can then be used to calculate what airflow would be required to create a reference pressure for comparison. The most common international reference pressure is 50 Pascals. In other words, how much airflow would be necessary to create 50 Pascals of pressure on a particular building?

8.2.1.1 Australian Standard AS/NZS ISO 9972:2015

Australia adopted ISO 9972, Figure 8.8 in 2015 as AS/NZS ISO 9972:2015 because it contains the essential elements of an airtightness testing for integration into regulation. In the National Construction Code 2019, the use of the standard was added as a path for demonstrating compliance with a requirement to seal the building envelope against air leakage in section V2.6.2.3. As the industry progresses eventually this testing procedure will be mandatory.

8.2.1.2 Use of airtightness testing in the National Construction Code

The threshold of 10 $m^3/(h \cdot m^2)$ at 50 Pa was set for dwellings in section V2.6.2.3 and Section 3.12.3 of Vol 1 and Vol 2 in the National Construction Code 2019 as a target that was both achievable by builders in Australia and within sight of other international standards.

"Inspection and measurement of the airtightness of the building envelope is common practice almost worldwide and is the state of the art in many countries. The measurement aims to identify weak points in the air barrier system and assist in repairing defects to prevent structural damage due to vapour convection. It is also often used to compare results to a numerical standard." [122]

8.2.2 International thresholds

Many other advanced countries have attempted to combat the problem of air leakage through stronger regulation.

Australia is experiencing the same problems. The southern states of the US have a similar range of climates and is therefore a good indicator of where the science will lead us.

Codes and standards around the world set air permeability targets to meet energy efficiency and build quality goals, which are often based on climate as well. For example, in the U.S., n_{50}-value of 3 or 5 is typical for climates similar to Australia's. In much of Europe, an n_{50}-value of between 1.5 to 3 and lower is typical.

The current benchmark in Germany is:

- All buildings must have an n_{50}-value of less than 3
- Buildings with ventilation systems must have an n_{50}-value of less than 1.5
- The state-of-the-art Passive House standard set very low n_{50} targets of 0.6 or better.

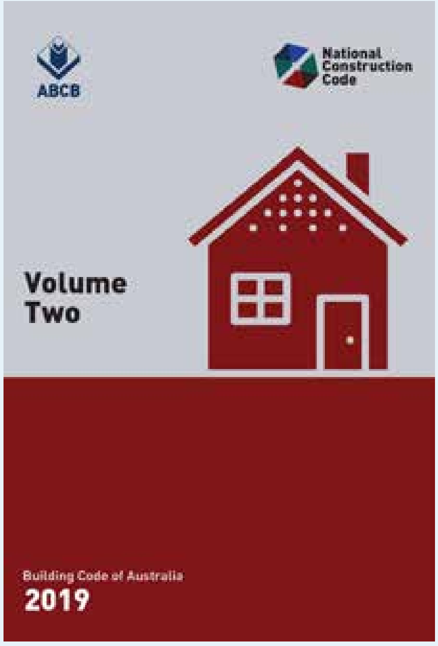
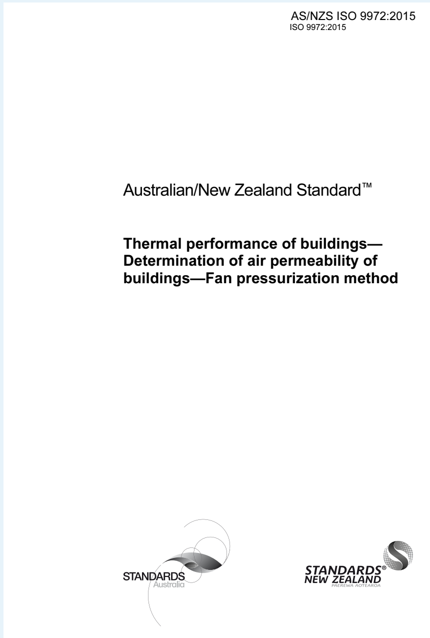


Figure 8.7: National Construction Code 2019, Volume 2, Section 3.12.3.2.a [120]


AS/NZS ISO 9972:2015
ISO 9972:2015

Australian/New Zealand Standard™

Thermal performance of buildings—Determination of air permeability of buildings—Fan pressurization method

STANDARDS Australia

STANDARDS NEW ZEALAND

Figure 8.8: AS/NZS ISO 9972:2015 [121]

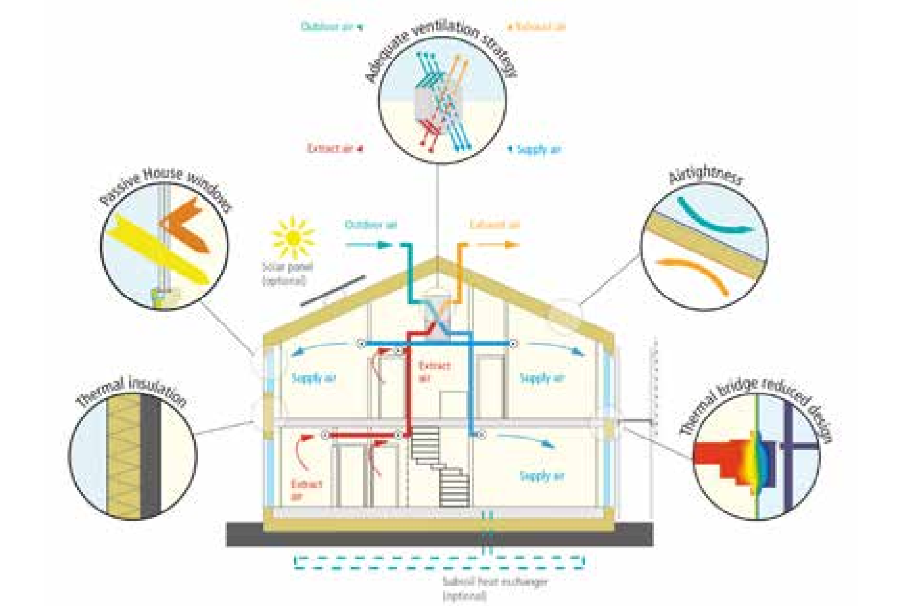


Figure 8.9: Passive House principles [123]

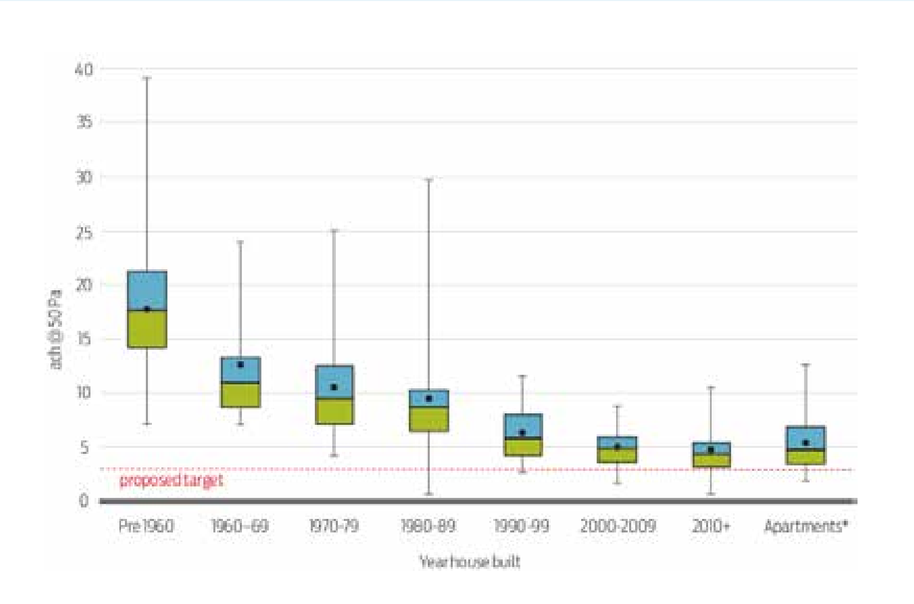


Figure 8.10: New houses are becoming considerably more airtight and a proposed target of 3 (n_{50}) @ 50 Pa is under consideration in New Zealand. [124]

The n_{50}-value of less than 3 for all buildings is based on the fact that air leaks lead to large heat losses and thus the energy balance of a building is worse than planned and calculated.

The n_{50}-value of less than 1.5 for buildings is based on the fact that ventilation systems must be able to control the air volume and thus the air exchange. In the event of leaks, air leakage enters the building: in the event of higher temperature differences between the outdoor and indoor climate (winter in Climate Zones 2–8) and in the event of an increased wind load (windy regions), this can be considerable amounts of air. This indicates that the ventilation system is not able to be regulated effectively.

The n_{50}-value of less than 0.6 is based on the fact that Passive Houses must above all have a predictable and very low energy balance and leaks lead to a large loss of energy. (Figure 8.9).

"Airtightness of the building. Uncontrolled leakage through gaps must be smaller than 0.6 of the total house volume per hour during a pressure test at 50 Pascal (both pressurised and depressurised)." Passive House Institute, Darmstadt [123]

The Australian Passive House Institute provides information and support in the planning, development and use of Passive House buildings and the application and implementation of the technology. It connects the demand with experts in Australia. The competence of the Passive House Institute Australia is on the known high international level. The experience reports about Passive Houses in Australia - in the planning and construction phase as well as in the use phase - are more than convincing: against mould in and on the construction and for high energy efficiency.

8.2.3 Will qE_{50} of 10 m³/(h·m²) at 50 Pa protect the structure from moisture damages?

A permeability of 10m³/(h·m²) at 50 Pa should be considered minimum practice, as it is not difficult or expensive to achieve. It addresses only some of the concerns raised by building scientists and regulators. While it may improve comfort relative to worse performance, it does little to address moisture problems apparent in today's more insulated structures.

Some consequences of excessively leaky structures are extreme energy waste and results in discomfort of occupants. Over time, the public may come to accept that discomfort due to the weather is merely an unavoidable fact of life.

For different leakage levels, there are important implications:

1. Leaky – Energy inefficient
2. Semi-Leaky – See Figure 2.7 "Moisture leak" in chapter 2 resulting in hygrothermal nightmare.
3. Tight – Ultimate control of energy and moisture for healthy and durable buildings.

In New Zealand, building envelope tightness has received increasing attention in recent years and technologies have been implemented in ever broader areas.

"…. This clearly shows that houses are getting more airtight, with nearly 75% of the post-2010 homes having an n_{50} of 5 or lower (see Figure 8.10 and the note below it). The infiltration rate in many of our new builds is significantly below 0.25 ACH because of the increase in airtightness. This means that we are doing better from the energy efficiency point of view, as there is less uncontrolled leakage …" [125]

8.3 Prefabrication

Factory controlled environments allow quality building components with well-engineered dedicated air barrier systems that only need minimal amount of work on site at connections to achieve outstanding airtightness results. Passive House level airtightness can easily achieved and is repeatable on all buildings from a single quality controlled factory..

Experience shows that prefabricated houses achieve high airtightness qualities due to the in-house standardised construction details. With the appropriate awareness, however, this is also feasible for the complete construction of the building on site. Passive House standards are still rarely implemented, but the technology and know-how for this is available in Australia Figures 8.11 & 8.12 .

The Blower Door technology is also often used to detect the weak points of airtightness in existing houses. During the positive pressure measurement, fog can be used inside the building, which entrains out of the building through air leakage pathways.

8.4 NatHERS – debated assumptions in NatHERS

Most homes in Australia receive are assessed under the Nationwide House Energy Rating Scheme (NatHERS), which computer software is used to rate building energy efficiency. The process primarily allows for increasing insulation, improving window performance, and optimising shading features to improve star ratings. It includes some basic assumptions for air infiltration through features such as; vented or non-vented downlights, and if bathroom exhaust dampers are present. These assumptions are directly related to the building code. The assessor is meant to itemise all these possible leakage paths in a building. There are three obvious problems with this:

4. The assessor must assume which leaks will be in the final building, even before the building is built.
5. The assessor usually assumes that a builder will complete all sealing required by the building code.
6. None of the incidental leakages between construction assemblies, light switches, GPO's, ceiling penetrations etc. that all allow moisture laden air into the construction are addressed.

The actual energy and health outcomes may differ from the calculated values. Alternatively the infiltration rates in energy assessments should be linked to actual building Blower Door verification. This was shown to be possible during the development of the New Zealand AccuRate version for the Home Energy Rating Scheme (Figure 8.13 A) and in early 2022 was released as an option in AccuRate Sustainability V2.4.3.21 SP1 in Australia in non-rating mode (Figure 8.13 B).

8.5 Why the indoor air exchanges with the outdoor air?

8.5.1 Forces at work

"Since water vapour dissolves in air, the envelope should be able to keep air moving along planned pathways, as far as possible. Leakage through gaps, cracks and holes will subvert strategies to control the diffusion of water vapour." [126]

8.5.1.1 Stack effect

Stack effect is a major driver of air movement into and out of a building. Because warm air is less dense than cold air, so it tends to rise to the top of a building. Colder air is denser, so it tends to sink to the lower parts of a building. This effect drives warm air up and out the air leaks at the top of a building in the winter. It also allows cooler air to leave through leaks and openings in

Figure 8.11: Photo courtesy of pro clima NZ

Figure 8.12: ISMART Building Group, WA

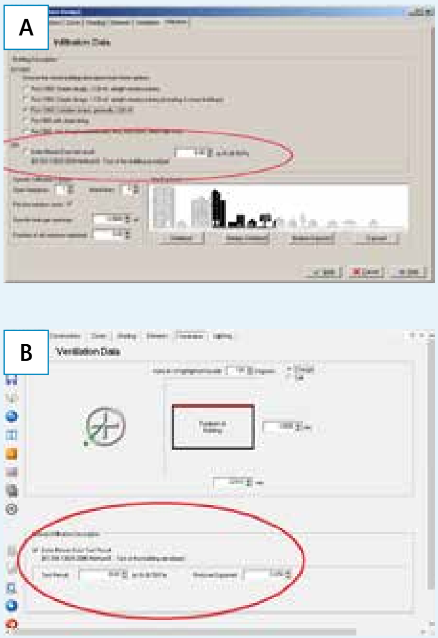


Figure 8.13: A) New Zealand AccuRate version for HERS B) AccuRate Sustainability V2.4.3.21 SP1 released in Australia in 2022 in non-rating mode

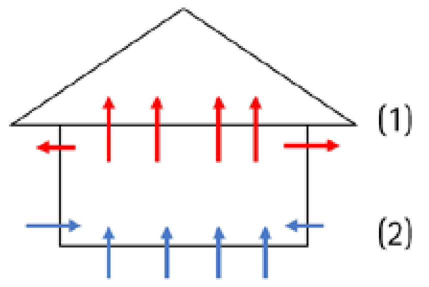


Figure 8.14: (1) Interior moisture transported into vulnerable roof space; (2) Air from unhealthy sources pulled into home

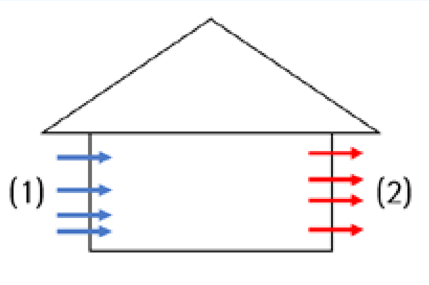


Figure 8.15: (1) Unconditioned air entering; (2) Conditioned air leaving

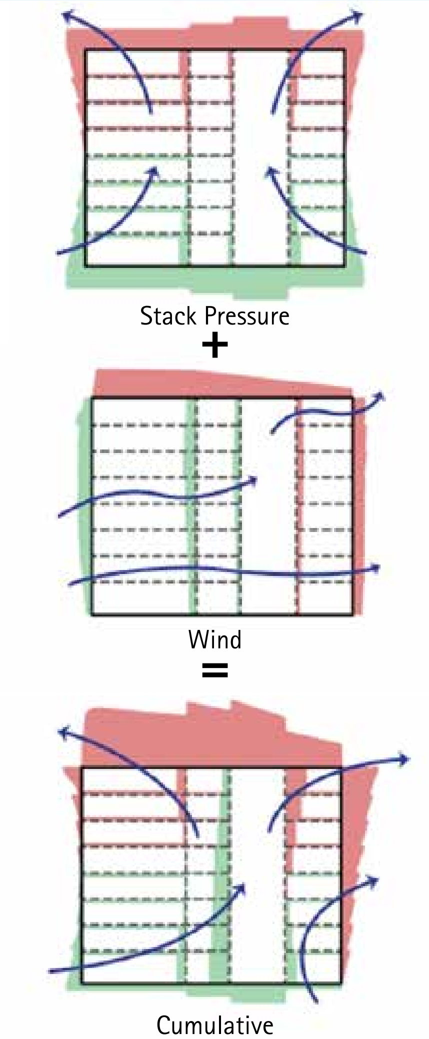


Figure 8.16: Cumulation of stack and wind pressure

the bottom of a building during the summer. These forces almost always exist in buildings. When air leaks are present, the forces induce moist airflow in and out of the envelope. The (World Health Organisation) WHO cites this as a concern for indoor air quality.
"…there is almost always a positive and a negative air pressure difference across the building envelope of detached houses and apartment buildings …" [127] (Figure 8.14 – 8.16)

8.5.1.2 Wind and mechanical pressures

When wind blows on a building, it generates positive pressures on some parts of the building and negative suction on other parts. The effect is short-lived and variable. When there is no breeze, there is no wind-induced infiltration. When wind is strong, it often results in energy waste and occupant discomfort.
Mechanical systems may generate pressures on a building envelope by design, for example resulting from basic ventilation system designs. However, mechanical pressures may also be generated unintentionally by poor design, and construction defects like leaky ductwork, and maintenance problems like dirty filters. In leaky buildings with significant air leakage paths, resulting pressures can create problems by drawing air and moisture into building envelope assemblies.

8.5.1.3 Infiltration is not ventilation

Because the forces outlined above are variable – dependent on the weather and operation of mechanical systems – they cannot be relied on for consistent ventilation. Infiltration is not a reliable source of consistent clean ventilation. Creating a tight building envelope and then introducing consistently designed and built ventilation is wise. A motto of building science holds true: "Build tight and ventilate right".
Major regulatory and advisory bodies promote such ideas in their standards and guidance. The World Health Organisation's Guidelines for Indoor Air Quality: Dampness and Mould states that: "It is difficult to control air pressure differences in normal and leaky houses … Pressure can be effectively controlled by ventilation only in extremely airtight houses." [128]
This is because control over building envelope pressure allows ventilation to take a more prominent role.

8.5.1.4 Ceiling

The force of stack effect is greatest at the top and bottom of a building. It is also greatest during the coldest or warmest weather coinciding with greater potential for condensation. All air contains water vapour, warm air is lighter than cold air, so warm air will rise. Water vapour is lighter than air itself and water vapour wants to move upwards. In wintertime upward movement of air and water vapour presents both energy leaks and moisture related issues. Stack-driven convection can carry moisture in or out of a building and deposit it as condensation on cold roof surfaces. (Refer to Chapter 7)

8.5.2 Health

There is robust evidence that cold and draughty homes are a contributing factor to negative health impacts on society overall. A study on U.K. population and housing conditions found:
"There are measurable effects of cold housing on adults' physical health, well-being and self-assessed general health, in particular for vulnerable adults and those with existing health conditions."
And for older people, "Effects of cold housing were evident in terms of higher mortality risk, physical health and mental health." [129]
In leading medical journals, studies of so-called Excess Winter Deaths in fact show distinct effects of sub-optimal temperature in buildings on all-cause mortality. In Australia, the effect was well documented. Poor comfort conditions and prolonged stress result:
"Despite the attention given to extreme weather events, most of the effect happened on moderately hot and moderately cold days, especially moderately cold days. This evidence is important for improvements to public health policies aimed at prevention of temperature-related health consequences". [130]
The importance of draught-proofing buildings for the sake of occupant health should not be underestimated.

8.6 History of the Blower Door

The history of the idea extends well back into the 20th century. One of the first published references to airtightness originated in Sweden in 1977 and spread to American researchers from there. Refining the idea into a consistent procedure capable of precise and repeatable measurement is the process of science. Applying the science to the realities of a competitive market is a challenge. The building industry needed a system that was affordable, but also simple, robust, and easy to transport and use. In 1986 for example, there were eleven firms in the U.S. manufacturing Blower Doors, but within a few years, the number of leading manufacturers fell to three. In Europe, a similar story of refinement and consolidation unfolded. Today, airtightness testing is highly advanced and relatively affordable, yet it retains its roots as a powerful qualitative assessment tool as well [131] (Figure 8.17).

Today's Blower Door manufacturers have taken advantage of modern technology with data recording and logging capabilities. Verification of collected data for use by building scientists and regulators is now happening at an extraordinary pace. The process is so well refined that it is trusted by regulators to verify performance targets.

In Australia, the Minneapolis Blower Door is now imported from the USA into Australia by Pro Clima Australia Pty Ltd and users are educated and trained in the technology in Australia and New Zealand by ATTMA. There are many competent and excellent experts in Australia who are available for measurements and consultations - you can find a list of current Blower Door testers at www.blowerdoor.com.au.

8.7 Who uses Blower Doors?

8.7.1 Builders – diagnostics

Builders can use airtightness testing systems during construction without the process of calculating exact results. They can do this to gauge workmanship, uncover defects, and identify strategies and designs that more reliably work. Construction systems, methods, materials and workmanship used to construct the floors, walls and ceilings of a building will impact the amount of air infiltration. The more surface area and the more complex a building's shape, the more joints are required to be sealed.

8.7.2 Developing testing in Australia

To reliably measure and verify air leakage performance for compliance with build standards, bodies like the Airtightness Testing and Measurement Association (ATTMA), a worldwide network of testing professionals, have organised to promote consistent, traceable measuring processes. The number of registered testers in Australia is growing every year.

ATTMA (Figure 8.18) was formed in 2002 to promote the testing and measurement industry and it supports its members by extending market awareness of the technology and the members' services. In 2016, it opened its membership to Australian and New Zealand testers as fellow supporters of excellence in the profession.

This shows that the knowledge of how to build airtight structures, achieve energy-efficient, damage-free and healthy buildings is available in Australia - the application and implemented on a broader scale is happening now.

It is important to remember that buildings constructed today will have their embedded performance and construction quality for at least 20 years, if not for the lifetime of the building extending beyond 50 years.

The experience of Germany in the 1990s shows that government regulation is highly effective at making a difference on a broad scale. It takes many to create a movement and typically a few ideologists to lead the way and show what is technologically possible.

8.8 Summary

- Airtightness systems are always best implemented on the inside of the insulation systems except for air-conditioned buildings in BCA Climate Zone 1 (tropical climates).
- Effective airtightness requires planning, suitable installation requirements, and verification.
- Continuity of the airtightness systems in the design phase can be made easy with a simple red pen test.
- Verification tool for airtightness in situ is the Blower Door.
- Airtightness may be expressed as n_{50} or qE_{50}.
- n_{50} is the air leakage as related to the building volume.
- qE_{50} is the air leakage as related to the envelope surface area.
- Airtightness controls airflow to prevent interstitial condensation. The tighter the better and a q_{50} under $2\,m^3/(m^2{\cdot}h)$ is desirable.
- Passive House sets international best practice for airtightness with an n_{50} target of 0.6 (Approximately qE_{50} of 0.6 $m^3/(m^2{\cdot}h)$ for houses)
- Infiltration is not ventilation. Airtightness with controlled ventilation can ensure the optimum level of fresh air is supplied all the time.
- NCC states airtightness targets which range from $10\,m^3/(m^2{\cdot}h)$ to $5\,m^3/(m^2{\cdot}h)$ depending on building class. However much lower is preferable for greater control of heat and moisture.
- Airtightness testing is regulated by the National Construction Code and references test standard AS / NZS ISO 9972:2015.
- ATTMA provides training and administrates the Blower Door operator competency scheme.
- Blower Door testing kits are available for purchase via pro clima.

Figure 8.17: Prehistoric Blower Door

ATTMA
The Air Tightness Testing & Measurement Association

Figure 8.18: ATTMA

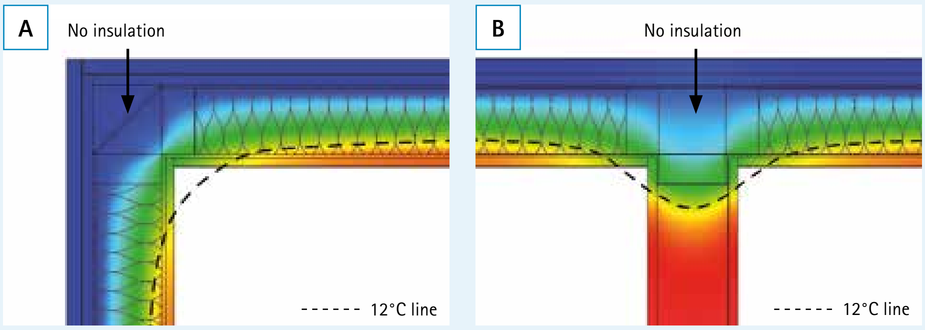


Figure 9.1: Computational modelling of a thermal bridge caused by geometry (a corner) and by material (missing insulation). A) Uninsulated corners cause thermal bridges. B) Uninsulated joints of integrated internal walls cause thermal bridges.

Figure 9.2: Typical uninsulated corners.

Figure 9.3: Typical uninsulated internal wall to exterior wall junctions.

9. Thermal bridges

Thermal bridges are spots in a construction where the insulating layer is interrupted or otherwise imperfect. A distinction is made between thermal bridges caused by geometry (geometric thermal bridge) and those caused by materials (structural thermal bridge).

9.1 Geometric thermal bridges

Thermal bridges caused by geometry can be found, for example, in corners and junctions of building elements. In these situations, the outside surface area is greater than the inner surface area allowing the outer surface to radiate more energy outward. The corners of buildings and fittings integrated in the external building envelope pose a particular risk of forming thermal bridges if the joints are inadequately insulated, or not insulated at all, see Figures 9.1 A) and B).

In Australia, the frames of buildings with masonry cladding are often constructed in such a way that there are two studs diametrically opposite each other at the corners of the building. There is typically no stud at the actual corner, creating an uninsulated void, a thermal bridge. This void is closed off by the wall wrap on the outside and by the two studs on the inside. It is only possible to insulate the outer corner before the wall wrap is fitted. However, this is not usually done during construction, so the corners remain uninsulated, see Figure 9.2.

Building envelopes with wooden cladding have a stud added in the corner of the building.

The same situation occurs at the joints of internal walls, where the stud for the internal wall is often facing inwards, right beside two posts of the exterior wall. Here again, the void between the two studs is closed off by the wall wrap and the stud for the interior wall and it is thus only possible to insulate it before the wall wrap is fitted, see Figure 9.3.

The corner of the building cannot be insulated by the person who installs the thermal insulation if the wall wrap has already been fitted. The same also applies to joints between exterior walls. Once the wall wrap has been fitted it is impossible to add more insulation from the inside.

Thermal bridges on this scale result in significant cooling of the surfaces of the inner lining, thus causing higher humidity and potentially condensation, and thus mould growth on the surfaces. Mould can grow

only with elevated surface humidity, not just if it is wet.
An uninterrupted layer of thermal insulation is difficult to achieve where there are fittings in the wall. It is very difficult to ensure adequate thermal insulation in the compartments, see Figure 9.4.
This is another place where thermal bridges occur, resulting in cooling of the internal surfaces and thus creating a risk of mould.

9.2 Structural thermal bridges

Structural thermal bridges due to the material are caused by using materials that have high thermal conductivity, e.g. metal, and in particular steel beams, see Figure 9.5. Steel beams, columns and other load bearing building elements are often used in light timber construction.
Steel components act as structural thermal bridges in wooden structures (see Figure 9.6 A and B) as well as in steel structures, such as steel frame buildings, see Figure 9.7. In such cases it is advisable to add a layer of thermal insulation to at least one side of the metal components. Heat is conducted out of a building by steel very fast in the winter, so steel components are always the coldest spots in any structure. This can reduce the surface temperature on the inside significantly, causing condensation to form either on the surface or within the structure.
A layer of thermal insulation should be put on at least one side (preferably on the outside) of steel components to reduce the effect of structural thermal bridges. Ideally, steel components should be insulated on all four sides, but this is not always practically possible.
In addition to posing a risk of mould and structural damage, thermal bridges also result in heat loss and higher heating costs.

Figure 9.4: Typically insulation and services compete for space.

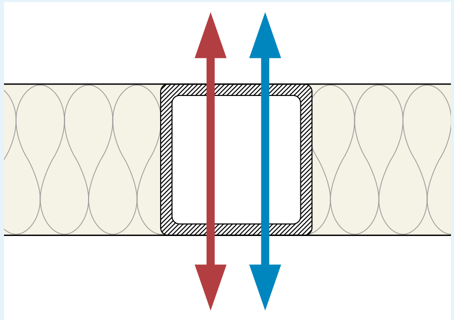


Figure 9.5: Schematic diagram of structural thermal bridges caused by materials. A steel support conducts the heat out of the building faster than the insulated compartment.

Figure 9.6: Insulate steel beams on at least one side, preferably on the outside

Figure 9.7: Insulate steel structures on at least one side preferably on the outside

Figure 10.1: Class 4 Vapour Permeable flexible WRB

Figure 10.2: Fully adhesive membranes over rigid board

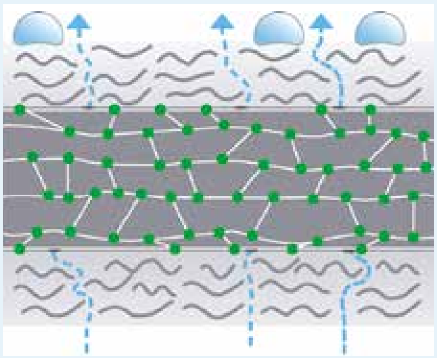


Figure 10.3: Active vapour transport with TEEE

10. Notes on planning and construction

10.1 Targets

Buildings should have a high level of protection against moisture penetration, which can cause mildew, mould, corrosion, and decay. Buildings need to achieve low energy consumption, low resource utilisation with high durability as well as delivering healthy indoor climate conditions. Planning intent and what happens in practice often differ because of inaccuracies in workmanship and when there are unforeseen effects/influences. Therefore, it is expedient to plan and build with as many safety buffers as possible, so that the planning goals achieve the desired results, even under difficult and adverse circumstances.

10.2 In Climate Zones 2 to 8

10.2.1 Weather Resistive Barriers (WRB)

WRB should have a high water vapour permeability. This includes both pliable and rigid WRBs. Pliable weather resistive membranes should have a vapour diffusion resistance of less than 0.88 MNs/g (class 4 permeable, AS/NZS 4200.1) or at least a combined vapour diffusion resistance less than 7.0 MNs/g (class 3 permeable, AS/NZS 4200.1) when using a pliable membrane and rigid board (Figure 10.1).
Rather than a microporous film technology used in competitors products, pro clima has developed a non microporous SOLID film, the TEEE membrane used in the pro clima SOLITEX EXTASANA® (for walls), SOLITEX MENTO® (for roofs) and SOLITEX ADHERO® (for walls and roofs, Figure 10.2). The moisture vapour transport mechanism occurs along the molecular chains via diffusion (Figure 10.3) and not through the pores. SOLITEX ADHERO® has the advantage that the sealing is glued and not stapled, which offers greater protection from driving rain. Please see pro clima instruction manuals for external weatherproofing of walls and roofs.
The higher the vapour diffusion resistance on the outside, the more condensation may form in the winter and the greater the risk of structural damage.

10.2.2 Aluminium foils

Aluminium foils should generally be avoided (Figure 10.4 A) in all constructions to provide long term durability and performance. This rule applies to all climate zones, not only where they are currently prohibited (Climate Zones 6 to 8). Vapour permeable materials and solutions should be favoured in all cases except in special scenarios where slightly more vapour resistance may be necessary due to climate or specialist building applications. Metal sheet bracing elements will act as vapour barriers in the same manner and should be avoided (Figure 10.4 B).

10.2.3 Airtightness

Without an airtightness layer, constructions might seem to work in some cases but considering not just vapour diffusion transport mechanism there is also the mechanism of convection which occurs in non-perfect constructions in a non-perfect world. Convection can transport much more water vapour and heat than diffusion. That's why an airtightness layer is recommended on the inside of the insulation for all construction assemblies, both wall and roofs. Because of possible back diffusion (reversal of vapour flow) in summer climate conditions a membrane with a humidity-variable vapour diffusion resistance, e.g. INTELLO® PLUS provides the ultimate performance. INTELLO® PLUS adapts its permeability to the ambient climate conditions: in winter climate conditions INTELLO® PLUS performs with a lower permeability (higher resistance) to protect the construction against entry of moisture and in summer climate conditions INTELLO® PLUS performs with a higher permeability (lower resistance) to allow transport and evaporation towards the indoor climate without entrapment (Figure 10.5). In this regard, INTELLO® PLUS is incorporated with TESCON® and CONTEGA® tape products utilising the water-resistant SOLID glue and the highly flexible ORCON® CLASSIC adhesive forming a complete system referred to as the INTELLO® PLUS Intelligent Air Barrier System.
Please see the pro clima online technical literature and application manuals for weatherproofing of walls and roofs, as well as air sealing of buildings using INTELLO® PLUS Intelligent Air Barrier (IAB) system.

10.2.4 Internal lining

To exploit the high degree of protection provided by intelligent moisture management, it is important that moisture can dry out into the building without any blockage.

It is therefore advisable to avoid diffusion-inhibiting wall or ceiling linings.
Wood-based materials (e.g. plywood) fitted over the airtightness membrane on the indoor side reduce the ability for moisture to dry out inwards and also pose the risk of summer condensation on the back of the boards, facing away from the room.
It is beneficial to use diffusion-open materials such as plasterboard. It is advisable to avoid high resistance finishes to the plasterboard such as vinyl wallpaper, semi-gloss, or gloss paints on the inside. Water based interior flat acrylic emulsion paints, and water glass (sodium and potassium silicate) paints are likely to be class 4 permeable, see Figure 10.5.

10.2.5 Permanently damp rooms

In residential buildings intelligent airtightness membranes can be used in all rooms with external walls and roof applications, even in rooms that are temporarily subjected to increased humidity levels such as bedrooms, bathrooms or the kitchen.
Buildings and rooms with permanently high levels of humidity such as swimming pools, saunas, garden centres or large-scale catering establishments etc., call for special consideration of their physical demands and must be fitted with an airtightness membrane with very specific properties.
Consultation with Pro Clima Australia during the design and planning stage is recommended for such buildings and constructions.

10.2.6 Moisture caused by residents and moisture in new buildings

10.2.6.1 Damp rooms (60/10 rule)

Case studies have shown that intelligent airtightness membranes need to meet certain requirements with regard to diffusion resistance. During normal use of residential buildings, the diffusion resistance should never be less than 10MNs/g to ensure that the building does not suffer structural damage. Here the 60/10 rule applies. This means that a humidity-variable (intelligent) air barrier membrane needs to have a vapour diffusion resistance of no less than 10MNs/g at an ambient average humidity of 60%.
In wet and humid rooms in residential buildings the relative humidity can be as high as 70 % at a temperature of 20 °C. INTELLO® PLUS humidity-variable membrane, which has a diffusion resistance of 20MNs/g at an average humidity of 60 %, provides ideal protection, even for these rooms, by adhering to the 60/10 rule (at 70% humidity of the air in the room and 50 % humidity in the insulating layer = 60 % average humidity). This means the building envelopes of residential buildings are adequately protected against moisture from the air and mould resulting from such moisture, see Figure 10.6.

10.2.6.2. Increased humidity during the building phase: Hydrosafe® value (70/7.5 rule)

In certain cases, buildings have a very high indoor humidity level of more than 90% during the construction phase when walls are being plastered or screed is being laid. The Hydrosafe® value quantifies the protection of insulated timber structures against increased indoor humidity caused by construction work (building moisture) during the construction phase. It specifies the water vapour resistance that a humidity-variable airtight membrane installed on the interior must have as a minimum to ensure that the insulation and structure itself are sufficiently protected against moisture during all phases of construction. A Hydrosafe® value of at least 7.5 MNs/g has been specified as offering sufficient protection at an average relative air humidity of 70 %.
INTELLO® PLUS achieves a water vapour resistance of greater than 10 MNs/g at an average humidity of 70 % (90 % air humidity in the room and 50 % air humidity in the insulation) and provides sufficient protection for building components even during the increased air humidity caused by construction work. Excessive indoor humidity during the construction phase over an extended period damages all materials and components in buildings and causes a build-up of dampness in them. This humidity should be allowed to escape quickly and continuously by systematically opening windows to provide ventilation. It may also be necessary to use dehumidifying ventilation systems (Figure 10.6).

10.2.7 The service cavity

The so-called service cavity has proven itself to be ideal in ensuring uninterrupted and simple provision of channels for electrical and/or water supply installations (Figure 10.7) within the construction. This is where an additional layer of battens is affixed for electrical installations after assembly and connection of the Intelligent Air Barrier system to the framing. Without a service

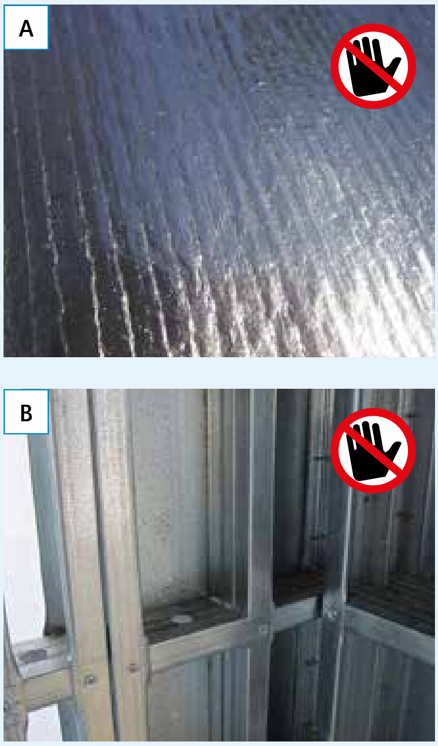


Figure 10.4 A: Aluminium foils; B: Metal sheet bracing

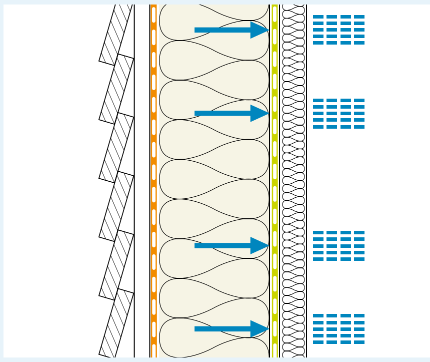


Figure 10.5: For constructions that are diffusion-inhibiting on the outside it is advisable to avoid diusion-inhibiting material on the inside. Intelligent moisture management using INTELLO® PLUS, however, ensures a high potential freedom from structural damage.

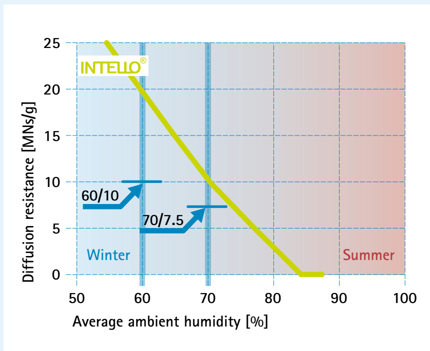


Figure 10.6: Damp rooms & building time

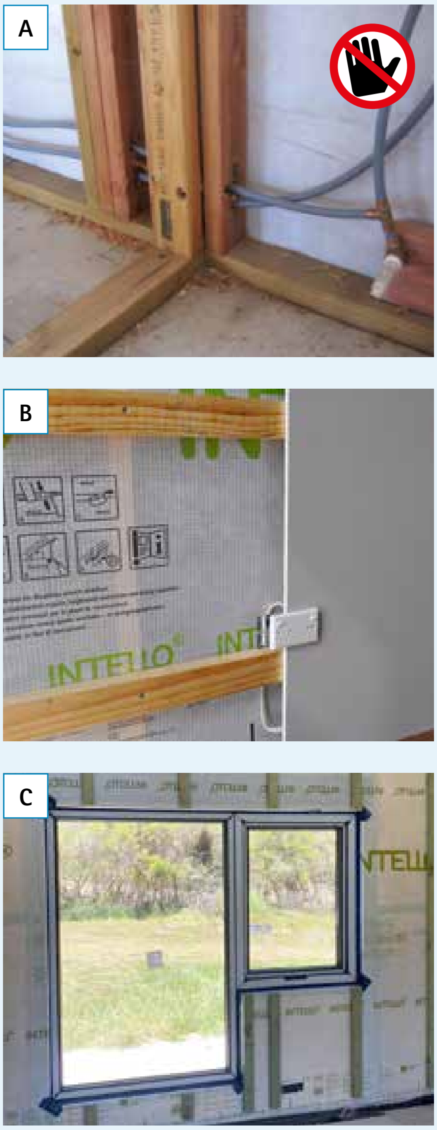


Figure 10.7: Cavity battens allow for better insulation and quality air barriers. A) No cavity battens; B) Horizontal cavity battens; C) Vertical cavity battens

Figure 10.8: Colour of roof or wall cladding affects the hygrothermal balance.

cavity the insulation and services are forced to share the same space (Figure 10.7 A) leading to compressed or missing insulation.
It is possible to install the cavity battens horizontally (Figure 10.7 B) or in vertical alignment (Figure 10.7 C) with the studs. The installation of a service cavity allows for non-compressed continuous insulation to be installed and fewer air barrier penetrations to deal with.
The inner lining panel is then fixed to these battens. The advantages of this alternative are the ease of laying and fixing the electrical installations to the framework and the high level of moisture protection provided to the building envelope, because the thermal insulation is not interrupted, and the air barrier membrane is left intact.
It takes much more effort to install and connect the airtightness membrane in building components without a service cavity because many penetrations are needed for outlets and switches. This results in additional time-consuming work.

10.2.8 Foam insulation

Foam insulation (i.e. PUR, PIR, XPS or EPS) usually has a higher diffusion resistance and lower moisture transport capacity. This means that foam used on either side of the structure inhibits drying in the direction of the side that it is placed. Foam insulation on the inside poses a serious barrier to back-diffusion and can severely limit construction moisture drying out in the early phases of occupation.
Foam insulation will always reduce the drying capacity of a structure and reduce its overall freedom from structural damage. Therefore, it should be used with caution. Fibrous insulation types (mineral wool, polyester, wood fibre, cellulose etc.) allow for greatest drying potential due to their extremely high vapour permeability and are ideal for constructions in all Australian climates to achieve durability, resilience to rain leaks and freedom from structural damage.

10.2.9 Drying potential towards the inside

An exterior construction detail (i.e. wall or roof) that has a higher vapour diffusion resistance towards the outside from inside has a potential condensation risk. A high safety margin against structural damage with INTELLO® PLUS occurs when the temperature on the outer side of the insulation is higher than on the inside to allow for back diffusion.
Regulations correctly incentivise lighter colours in warmer climates to reduce summer heat absorption to reduce overall peak cooling demand (Figure 10.8). However, the flip side to this is that we reduce the average annual temperature of the outside layers of the building components. This increases the risk of moisture damage.

10.2.10 The right time for installing the airtightness membrane

When installing the insulation and airtightness membrane, it is important that the insulating material is covered by an intelligent air control layer as soon as it has been put in place, especially if this is done in the winter. Without the airtightness membrane the humidity from the room can enter the construction unhindered, then cool down (especially at night) in the insulation and cause condensation to form within the insulated structure.
As described in section 10.2.7, constructions with a service cavity are recommended, as this allows the Intelligent Air Barrier membrane to be left intact and simplifies installation.
The insulating material and airtightness membrane should be laid step by step. The airtightness membrane is connected to the adjacent building components immediately after having been laid. This procedure avoids condensation forming in the region of the connections to adjacent components.
Care needs to be taken not to install an Intelligent Air Barrier (IAB) over building elements with water content greater than 18%, as the construction assembly may trap moisture, making it difficult to effectively dry.

10.2.11 Dry building materials when installing thermal insulation

The timber used for the framing should be dry (<18% moisture content by mass [M-%]) when the thermal insulation is installed and when the airtightness layer is put in place. All materials should be protected from the weather (Figure 10.9) and installed dry such as thermal insulating materials, service cavity battens and interior linings.

10.2.13 Recycling and eco-friendliness

To permit easy recycling, the IAB membrane INTELLO® PLUS is 100% polyolefins – the special membrane is made of polyethylene copolymer, the fleece and the fabric are made of polypropylene.

10.3 In Climate Zone 1

10.3.1 Weather Resistive Barriers (WRB)

The WRB should have a lower permeability on the outside to reduce the diffusion flow from the outside to the inside. Ideally, the diffusion resistance should be slightly less than 7 MNs/g, i.e., in the upper range of class 3 permeability (AS/NZS 4200.1). A pliable membrane with a rigid board is suitable for this. This is state of the art any-way because of the storms and winds in climate zone 1. The most suitable pliable membrane is SOLITEX EXTASANA ADHERO®, which is fully adhered to the rigid board over its entire surface. This protects the construction because the water barrier membrane is not compromised by mechanical fastenings such as staples. The full-surface bonding offers no points of failure against the wind and rain.

This has been already described in 10.2.1. The SOLITEX EXTASANA ADHERO® with monolithic interlayer has an extremely high resistance to driving rain with a water column of over 10,000 mm. The TEEE polymer technology results in extremely high tolerance to UV light (180 days allowed exposure prior to cladding) and continuous operating temperature of up to 100°C making it perfect for tropical environments, behind dark cladding (Figure 10.10).

The system can be used for the roof and the wall and has decisive advantages for airtightness and therefore humidity control.

10.3.2 Aluminium foils

Aluminium foils, as they have no vapour diffusion capacity, create a risk with no ability to release moisture to the outside. A fully bonded WRB of Class 3 offers the advantage to prevent humidity diffusion from outside but also allow for some drying capacity when required. It remains as vapour permeable as possible and is only as vapour resistive as necessary to deliver a good outcome.

Perforated foil products also do not provide air or water resistance and should not be used in applications where a WRB or IAB are required.

Aluminium foil products also sweat, and the perforations do not effectively provide drying capacity to the wall or roof structure.

10.3.3 Airtightness

Since it is warmer outdoors than indoors in Climate Zone 1, the airtightness layer must be on the outside. The WRB fulfils two functions at the same time here:

1. Protection against weather-related loads such as wind and rain, and
2. The airtightness protects from uncontrolled air exchange from the warmer outside to the colder inside.

When pliable WRB membranes are used for airtightness, they must be made from an airtight vapour permeable material, such as membranes with a non-porous TEEE-layer. as included in the SOLITEX EXTASANA ADHERO® or that of other SOLITEX® exterior membranes.

The membranes are bonded to each other in an airtight manner and connected to the adjoining building components, such as windows and doors, in an airtight manner.

The WRB pliable membrane/airtightness layer is exposed to high moisture loads - from driving rain as well as from outdoor humidity. The connections should therefore maintain optimum water resistance. The pro clima adhesive membrane SOLITEX EXTASANA ADHERO® and the tape TESCON EXTORA® does not have the SOLID glue have a high water resistance due to the SOLID adhesive and the highly flexible ORCON® CLASSIC adhesive guarantee high durability even in rain and high humidity. Together they form the pro clima WRB/exterior air barrier system.

The pro clima technical team will be happy to advise you on the planning and execution of airtight execution in Climate Zone 1.

10.3.4 Internal lining

Since the diffusion flow in Climate Zone 1 is from the outside to the inside, there should not be a higher diffusion resistance on the inside than on the outside, or in other words, the amount of moisture that penetrates from the outside (through the WRB) should be able to dry out again on the inside (internal lining). It is advisable to avoid high resistance finishes to the plasterboard such as vinyl wall paper, semi-gloss or gloss paints on the inside. Water based interior flat acrylic emulsion paints, and water glass (sodium and potassium silicate) paints are likely to be class 4 permeable.

10.3.6 Moisture caused by residents and moisture in new buildings

The indoor humidity should be at a comfortable level, i.e. only a low or medium and not a high humidity load. This can be achieved, for example, by air conditioning with dehumidification.

Figure 10.9: Framing should be protected from rain and below 18 % moisture content by mass [M-%].

Figure 10.10: UV and Heat Stability – Tropical strength.

10.3.7 Service cavity

A service cavity is not required in Climate Zone 1 because the airtightness layer is on the outside. However, a service cavity will still allow for non-compressed quality insulation installation.

10.3.8 Dry building materials when installing thermal insulation

It is expected that timber has higher moisture content in the tropics. However the timber used for the framing should still be lower than 18% moisture content by mass [M-%] when the thermal insulation is installed. All materials should be protected from the weather and installed dry, including thermal insulating materials, service cavity battens and interior linings.

10.4 Construction Solutions

10.4.1 Weather Resistive Barriers

Figure 10.11: Drainage battens applied vertically.
Photo courtesy of Lou Projects.

Figure 10.13: Horizontal battens fixed over vertical drainage battens.
Photo courtesy of Carland Constructions Pty Ltd

Drainage battens
Vertical drainage battens are ideally fixed over the structure to clamp the membranes on the roof and walls (Figure 10.11). These have two functions, providing a continuous clamping of the membrane to keep it secure and the vertical orientation spaces the cladding away from the SOLITEX EXTASANA® allowing for drainage and a ventilation pathway. The minimum recommended batten depth for the battens is nominal 20 mm (Figure 10.12) which equates to 20,000 mm² of free airflow area which is enough to effectively remove moisture from behind any cladding system but will depend on the inlet and outlet openings.
In some circumstances a second set of horizontal battens are required (Figure 10.13). A second set of battens is typically only required when cladding panels or boards are fixed in the vertical orientation (Figure 10.14).

Figure 10.12: Vertical wall battens (min. 20 mm) facilitate drainage and ventilation.
Photo courtesy of Craft Building Pty Ltd

Figure 10.14: For vertical cladding horizontal battens with vertical drainage battens.
Photo courtesy of Evan Graham Master Builder Pty Ltd

Figure 10.15: Temporary fixings for brick veneer.
Photo courtesy of Passive House Construction Products Victoria

Temporary fixing

When masonry veneer cladding is used there is typically a time lag between the SOLITEX EXTASANA® being applied and the bricks being laid. The brick ties themselves can be suitable fixing for the membrane, but it is wise to plan for temporary fixings that are suitably strong to withstand expected wind conditions until the bricks are fully laid (Figure 10.15).
The SOLITEX EXTASANA® may be applied in successive layers as the brickwork is laid or the house fully wrapped before starting the brickwork. In which case temporary fixings are recommended.
Due to the TEEE technology used in pro clima membranes makes it is highly resistant to alkaline conditions and therefore unaffected by mortar droppings in brick cavities (Figure 10.16). Microporous polyolefin based interlayers on the other had can be damaged when used in this corrosive environment affecting their long term water and air barrier properties.

Figure 10.16: Alkaline resistant TEEE Technology.
Photo courtesy of Granted Constructions

Figure 10.17: Prior planning for fixing of membrane around penetration.
Photo courtesy of Sanctum Homes

Figure 10.19: ROFLEX or TESCON EXTOSEAL® used to seal pipe penetration.
Photo courtesy of MVH constructions Pty Ltd

External penetrations

Figure 10.17 shows an innovative approach to ensure the exterior flexible membrane is supported around the pipe penetration. The carpenter has supplied a round timber fixing point so the flexible SOLITEX EXTASANA® can be stapled, easily taped and sealed with a ROFLEX grommet.
KALFEX grommets can be used internally and externally and provide a simple, quick, and effective seal where cables penetrate the exterior membranes (Figure 10.18). Ensure KAFLEX are planned for in the design where no alternative cable routing options are available.
Large cables and small pipes can be sealed using ROFLEX 20 with integrated flange. Larger ROFLEX grommets can be used all the way up to 320 mm diameter pipes. Alternatively, the highly flexible and malleable TESCON EXTOSEAL® sill tape can be used to seal almost any shape penetration including pies (Figure 10.19). Planning between trades is essential for correct timing of installation of the pro clima penetration sealing products.

Figure 10.18: KAFLEX duo used to seal two flat cables.
Photo courtesy of MVH constructions Pty Ltd

Figure 10.20: Vents at bottom of wall provide drainage and some venting of the wall cavity. Photo courtesy of Eclipse Passive House Pty Ltd

Figure 10.22: Brick veneer vent openings. Photo courtesy of Granted Constructions

Wall vents

The drainage of wall systems can be achieved with very small gaps 5-10 mm between the cladding and the WRB. However, for best drainage and drying a minimum of nominal 20 mm cavity is recommended at bottom vents (Figure 10.20) and top vents (Figure 10.21) targeting 10,000 mm² of open area for each vent.

The brick mortar vertical openings required by AS 3700 [133] amounts to 76 mm high opening by the width of the mortar joint at maximum centres of 1200 mm. This equates to every 5th brick and a total of 633 mm² of ventilation opening per metre of wall. Usually centres are closer, pro clima recommends every 3rd brick, typically 900-1000 mm² of ventilation opening per metre of wall. These perpend opening should be included at the bottom and top of the wall and below and above all window openings (Figure 10.22) with correctly design flashings in accordance with pro clima recommendations.

This is significantly less than a lightweight cladding. However, brick veneer has the added advantage of thermal buffering due to the high heat capacity in the bricks evening out night-time minimum temperature extremes on the WRB layer.

Figure 10.21: Outlets at the top of the wall with bottom vents provides a fully ventilated cladding assembly.
Photo courtesy of Eclipse Passive House Pty Ltd

Figure 10.23: SOLITEX EXTASANA ADHERO® over rigid substrates behind architectural cladding.
Photo courtesy of Scholten Group

Rigid boards & SOLITEX ADHERO®

SOLITEX ADHERO® over rigid substrates provide a robust weatherproofing solution particularly for high wind areas. With a completely continuous WRB as the starting point. The fixing of the battens systems may be timber or metal and may be butyl sealed depending on the desired pressure limits. TESCON® NAIDECK can be used to achieve super weathertight solutions around fastener penetrations, and is ideal for high rain and wind scenarios in the tropical regions of Australia or exposed sites in high wind areas (Figures 10.23 & 10.24).

Figure 10.24: SOLITEX EXTASANA ADHERO® behind a drained and ventilated cavity system.
Photo courtesy of Passive Not massive

Figure 10.25: Sloped sill trimmer to shed water outwards on the surface of the TESCON EXTOSEAL®.
Photo courtesy of Sanford Build Co Pty Ltd

Figure 10.27: Applying CONTEGA® EXO.
Photo courtesy of Passive House Construction Products (TAS) Pty Ltd

Figure 10.29: Flush window sealed with TESCON EXTORA®.
Photo courtesy of Eclipse Passive House Pty Ltd

Figure 10.31: Battens stop shirt to allow tape joints.
Photo Courtesy of Lou Projects Pty Ltd

Window connections

TESCON EXTOSEAL® is a butyl sill tape with an acrylic adhesive, used for window reveals. It will entrain the butyl into screw threads when screwed through into the jambs. Best practice suggests that fastening penetrations into the horizontal part of the sill should be avoided where possible. Good practice is to slope the sill trimmer at a 5° slope which facilitates drainage outwards if any water penetration should accidentally occur around the windows (Figure 10.25). pro clima bonding technology adheres extremely well to metal flashings when clean and free from residue. This enables optimum integration of drainage pathways and flashings with long term durable connections (Figure 10.26).

The CONTEGA® products are used for sealing in windows, however the build sequence must be such that the WRB's and TESCON EXTOSEAL® are installed prior to the windows. This allows the CONTEGA® products to be applied to the windows before they are fixed into the openings (Figure 10.27).

Well installed windows consist of a front deflection seal and a back airtight seal using TESCON® or CONTEGA® products (Fig. 10.28). These two lines of defence work in combination to create a pressure equalised joint connecting the window to the WRB system. The joint can be filled with fibrous insulation to allow for maximum drying potential or open cell low expansion spray foam. Filling with insulation allows for maximum thermal performance of the joint, while maintaining watertightness and drying potential.

Windows may be positioned toward the inner of the reveal frame or toward the outer of the frame reveal. Flush fitting with the exterior WRB drainage plane surface allows for quick and easy front seals using standard TESCON EXTORA® (Figure 10.29).

If the windows are proud of the drainage plane alignment of the front of the window frame with a lightweight cladding material abutting is possible. TESCON EXTORA® PROFIL may be used to seal this junction quickly and easily (Figure 10.30).

Special attention to build sequencing is important when weather sealing the windows in. Battens fixed around the window reveals can make it difficult to tape the window connections if placed too close to the window opening. If battens are fixed prior to window fitting it is best to allow a gap so tape connections can be made (Figure 10.31 & 10.32).

In Australia windows are often installed prior to the walls being wrapped. This can still be achieved with proper planning. But as

Figure 10.26: pro clima bonding technology to metal flashings.
Photo courtesy of Sanford Build Co Pty Ltd

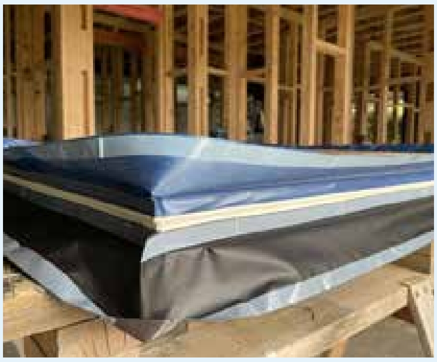


Figure 10.28: CONTEGA® EXO and CONTEGA® IQ for front and back seals.
Photo courtesy of Compound (NZ)

Figure 10.30: Proud window sealed with TESCON EXTORA® PROFIL.
Photo courtesy of Passive Builders Group Pty Ltd

Figure 10.32: Batten position allows for CONTEGA® EXO connection.
Photo Courtesy of Builders Declare Australia Pty Ltd

utmost importance it is necessary to apply the same attention to detail if the sequencing is swapped. A prefitted window reveal can be achieved with the same front and back seals and window dressing detail by leaving a WRB flange to connect into (Fig. 10.33).
Windows are often supplied with pre-fitted timber reveals or fitted into custom built reveals. The reveal itself can be sealed to the WRB or framing system using TESCON® tape range. The weatherproofing can then be achieved according to window manufacturer's details between the reveal and the window frame (Figure 10.34).

Figure 10.33: Pre-fitted window ready to accept WRB connection.
Photo Courtesy of Sanctum Homes

Figure 10.34: TESCON EXTORA® seal to the window reveal.
Photo Courtesy of Sanctum Homes

Roofing (ventilation)
pro clima products can be installed in the traditional method as defined in AS 4200.2-2017. Draped over the structural members and sagged to facilitate drainage into the gutter (Fig. 10.35). However, there are performance enhancements to be gained from modified construction practice for better drainage, thermal performance, condensation management, ventilation pathways, long-term durability of the membrane and therefore of the entire roofing system. Low slope skillion or cathedral style roofing as low as 5° pitch should incorporate SOLID sheathing and a batten and counter batten system to promote drainage, and ventilation (Figure 10.36). The vertical battens are ideal to ensure the membrane is held in place along the entire length of the rafter. The minimum vertical batten height should be nominal 20 mm (Figure 10.37). With larger counter battens ≥40 mm summer performance is further improved through better purging of heat via convection (Figure 10.38). The knock-on effects to fascia heights, eave and valley design need to be considered. Proper planning in the design phase is necessary to resolve the details at eaves, fascia's, valleys to achieve drainage of the membrane.
When installing the ASV system safety needs to be considered by the designers and builders to ensure a quality installation can be achieved (Fig. 10.39).
The membrane under the battens is a similar process to standard tile roofing membranes where they are laid under the battens and progressively work upwards from the eaves in successive layers. The vertical counter battens may not be fully continuous (Fig. 10.39), however in high wind zones heavier membranes and continuous counter battens may be necessary. The horizontal fixing battens are fixed over the vertical counter battens. The size of these battens may need to be upsized to 35 x 70 mm or even 45 x 90 mm so they can canterlever to create gable overhangs (Fig. 10.40).

Figure 10.35: High pitched roofing.
Photo courtesy of Passive House Construction Products (VIC) Pty Ltd

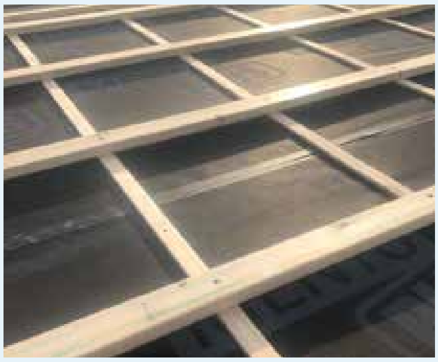


Figure 10.36: Low pitch roofing.
Photo courtesy of Sanford Build Co Pty Ltd

Figure 10.37: Min. 20 mm counter batten height

Figure 10.38: Larger batten size.
Photo courtesy of Our FabHaus Pty Ltd

Figure 10.39: Working safely.
Photo courtesy of Sanford Build Co Pty Ltd

Figure 10.40: Batten size and cantilevered eaves.
Photo Courtesy of Evan Graham master Builder Pty Ltd

Roof to wall connections at eave

In skillion and cathedral roof systems it is best to seal the ends of the rafters to prevent air movement up the stud cavity from the subfloor and into the rafter bays. This can be achieved by connecting the SOLITEX EXTASANA® to the bottom of the SOLITEX MENTO® roofing membrane that is shedding water to the gutters. This connection can be made using ORCON® CLASSIC (Figure 10.41) or TESCON EXTORA®.

With extended rafters the SOLITEX EXTASANA® will need to be sealed around the rafters using TESCON EXTORA® (Figure 10.42).

Alternatively, the roofing membrane can be connected into the wall membrane (Figure 10.43). When using continuous rafters, they will always need some careful attention to seal around the rafters with TESCON EXTORA®.

With good planning the SOLITEX MENTO® can be connected into the wall membrane without continuous rafters. The eave overhangs can then be "attached" as outriggers or a framed assembly. This ensures absolute continuity of the roof WRB to the wall WRB (Figure 10.44).

Eave ventilation detailing as inlets to the roof assembly differ slightly for timber fascia and metal fascia. For timber fascia it is relatively easy to drain and ventilate behind the fascia (Figure 10.45).

A double fascia is a tidy and elegant way to allow air in and incorporate invisible mesh. The front fascia holds the gutter assembly and the back fascia the water is designed to drain over (Figure 10.46). The gap between the fascia boards can be enlarged to suite the ventilation requirements.

Figure 10.41: Windtight details at eaves. Photo courtesy of Passive House Construction Products (TAS) Pty Ltd

Figure 10.42: Sealing around extended rafters. Photo courtesy of Passive House Construction Products (TAS) Pty Ltd

Figure 10.43: Connection of roof WRB into wall WRB.
Photo courtesy of Passive House Construction Products (VIC) Pty Ltd


Figure 10.44: Outriggers or "attached eaves". Photo courtesy of Evan Graham Master Builder Pty Ltd


Figure 10.45: Allowing for ventilation inlet at eave.
Photo courtesy of Eclipse Passive House Pty Ltd


Figure 10.46: Double facsia with ventilation & drainage gap.
Photo courtesy of Eclipse Passive House Pty Ltd

Figure 10.47: Pre-planning to drain behind metal fascia.
Photo courtesy of I-Smart Building Group

Figure 10.49: Bonding membrane to metal fascia.
Photo courtesy of Passive House Construction Products (TAS) Pty Ltd

Figure 10.51: Asthetic design of inlet vents.
Photo courtesy of Craft Homes Limited (NZ)

Roof eave drainage & ventilation

For metal fascia systems there are a range of planning issues. Typically, the roof cladding levels are all derived from the fascia which is installed first. Pre-installing a strip of membrane at the eaves prior to the metal fascia being installed can allow a behind fascia ventilation and drainage pathway. (Figure 10.47).

It is possible to work with the standard metal fascia install process by which the fascia is installed first. The roofing membrane can then be installed such that the membrane is adhered to the top of the fascia using DUPLEX, trimmed off and covered with a perforated mesh for vermin and/or ember protection (Figure 10.48 – 10.50). The perforated mesh also allows a level of UV protection to the membrane. Although this is more standard build sequencing standard gutter clips that fix over the top edge of the facia will not work. So alternative face mounted guttering systems need to be used.

Draining behind the fascia can be achieved with careful detailing and ventilation drainage slots behind the fascia. The drainage openings can be made with custom grilles (Figure 10.51 & 10.52) but in many cases off the shelf mesh products can be designed in.

Figure 10.48: Draining over metal fascia.
Photo courtesy of Passive House Construction Products (TAS) Pty Ltd

Figure 10.50: Vermin mesh and UV protection.
Photo courtesy of Passive House Construction Products (TAS) Pty Ltd

Figure 10.52: Custom made vent grille.
Photo courtesy of Craft Homes Limited (NZ)

Figure 10.53: Membrane over ridge.
Photo courtesy of I-Smart Building Group

Figure 10.55: Vermin mesh at ridge gap.
Photo courtesy of TruLine Construction

Roof ridges

Ridge ventilation is necessary to achieve ventilation within the ASV system. The size, open area of the outlets is predominantly driven by the requirements of the ASV between the membrane and the roof cladding. This may be as little as 50 cm² per linear meter of ridge which can be achieved by the cross-sectional area of the corrugations in a metal roof sheet. The ridge needs to account for this outlet area for both side of the roof (Figure 10.53). In strong ventilation strategies with 100 cm² or more per linear meter of ridge special outlets needs to be incorporated.

Tiled roofing has specialist proprietary products which allow dry fixed ridge capping that incorporate ventilation openings. In roof structures with trussed attic voids it is recommended that this space be ventilated. This means the membrane should not be continuous over the ridge and a gap must be left (Figure 10.54). Protection for vermin (Figure 10.55), bushfire embers or strong wind water blow back into the ridge should be considered in the detailing.

Figure 10.54: Gap in WRB at ridge to venitlate the attic.
Photo courtesy of TruLine Construction

Figure 10.56: WRB continuous under valley boards.
Photo courtesy of Passive House Construction Products Victoria

Figure 10.58: Counter batten system and fascia height.
Photo courtesy of Passive House Construction Products Victoria

Roof valley

When considering valley design, it is necessary to plan this well. The roofing WRB should be a continuous second line of defence that is installed under the whole valley section. This means that the valley may need to be lined with the WRB prior to valley boards (Figure 10.56) and/or trays (Figure 10.57) being fitted.

With the ASV system the valley may sit at a different height in relation to the fascia. If the facia is sitting high, it may interrupt the ability to install the valley tray to drain into the gutter. If the top edge of the fascia is sitting equal to the top of the vertical counter battens, the void space between the top of the fascia and the underside of the roof sheeting will need to be appropriately vermin proofed and special attention to the detailing at valleys incorporated to allow drainage of the valley tray (Figure 10.58).

Figure 10.57: WRB continuous under valley trays.
Photo courtesy of I-Smart Building Group

Roof upper storey

Connections between roofing membranes and walls to the upper storey can be approached using the first and second line of defence principle. This means the SOLITEX EXTASANA® from the upper storey should overlap onto the SOLITEX MENTO® and be taped and sealed. This detail is then a completely continuous drainage layer. The cladding as the first line of defence deflects the rain and should be separated away from the membrane system (Figure 10.59).
Apron flashing can be placed such that they drain from the wall WRB by being fixed behind the wall battens (Figure 10.60) or drain the water from the cladding only if the flashing is fixed to align with the front of the wall battens.

Figure 10.59: WRB as drainage layer at roof to wall connections.
Photo courtesy of Passive House Construction Products Voctoria

Figure 10.60: Flashing from roof to upper walls.
Photo courtesy of Enduro Builders

Special notes

Penetrations for solar power cables will be encased in conduit and can be quickly and effectively sealed using the ROFLEX 20 integrated tape grommets for a weathertight solution (Figure 10.61).
Fully wrapping eaves with SOLITEX® membranes can achieve completely enclosed rafter or trussed roofing systems. Care needs to be taken as any accidental water event can direct water behind the WRB or behind the soffits. (Figure 10.62). TESCON® NAIDECK used on roofing battens provides ultimate weathertight roof membrane assembly.
Skylights needs special detailing attention. The most difficult interface is the top edge which need special attention to ensure water is directed away from the top edge using slanted drainage systems, correct overlaps/underlaps and membrane continuity. High level of detailing should be employed in the design phase at these junctions to ensure drainage (Figure 10.63).
SOLITEX MENTO® connect versions have integrated tape that provides excellent bonding and water hold out when adhesive strips are bonded to each other (Figure 10.64). This is the recommended connection method when possible.

Figure 10.61: PV conduits sealed with ROFLEX 20.
Photo courtesy of Truline Construction

Figure 10.62: Wrapping eaves. Passive House Construction Products Victoria

Figure 10.63: Skylights and drainage.
Photo courtesy of Sanctum Homes

Figure 10.64: SOLITEX MENTO® connect self-adhesive zones

10.4.2 INTELLO® PLUS

Figure 10.65: Photo courtesy of pro clima NZ

Figure 10.67: Photo courtesy of I-Smart Building Group

Connection strips

The INTELLO® PLUS Intelligent Air Barrier system must be continuous to maintain its vapour management requirements. INTELLO® conneX is a strip of humidity variable INTELLO® membrane which can be pre-loaded into the construction system at difficult structural junctions during framing stage. In particular where the walls meet the external walls (Figure 10.65) or partition walls meet the roof truss (Figure 10.66) or roof rafters. Careful planning is required as this product needs to be installed at framing stage in preparation for installation of the INTELLO® PLUS Intelligent Air Barrier system after the building is weathertight.

For trussed roofs it is possible to use the INTELLO® conneX over the top plates of the supporting walls (Figure 10.67). When the trusses are fixed over the walls the INTELLO® PLUS can connect into the strips to create a continuous ceiling air barrier.

Figure 10.66: Photo courtesy of pro clima NZ

Figure 10.68: Installation of INTELLO® PLUS at wall sections

Wall installation

INTELLO® PLUS is fixed to walls using staples for timber and DUPLEX double sided tape if fixing to metal frames. The membranes are usually installed horizontally on walls starting at the bottom of the wall (Figure 10.68). Ensure that enough overlap onto flooring is allowed to ensure durable connections can be made using ORCON® CLASSIC. Special consideration should be given to the type of flooring if the INTELLO® PLUS is to be connected the flooring material must be and air barrier material. Battens systems and service cavities are recommended for best long-term fixing and strength.

Figure 10.69: Stapling of INTELLO® PLUS. Photo courtesy of Bright Haus

Ceiling installation

INTELLO® PLUS is fixed to ceilings using staples for timber (Figure 10.69) and DUPEX double sided tape if fixing to metal frames. Planning the orientation of the lay may make the install easier and ensure connections into the walls at the corners of the room are easy to make. Battens systems and service cavities are recommended for best long-term fixing and strength.

Figure 10.70: Well implemented INTELLO® PLUS IAB connections in dorma.
Photo courtesy of I-Smart Building Group

Dorma detailing

Detailing of dorma windows needs to be considered for internal and external corners and tricky junctions (Figure 10.70). The most difficult part for airtightness systems is corner junctions of which there are many to be made in tight corners in dormas. Planning where the overlap connections will be made will make sealing easier.

Figure 10.71: Apply primer to stabilize the surface

Wall to floor connections

Floor connections need to be planed and suitable products arranged to be on site. Connecting to porous substrates that may be dusty, dirty or flaky can be achieved using TESCON® PRIMER RP (Figure 10.71). TESCON® PRIMER RP impregnates the surface binding loose surfaces to achieve full adhesion and long-term durability when TESCON® tapes are used to or when ORCON® CLASSIC is applied over (Figure 10.72). ORCON® CLASSIC should be allowed to dry out until tacky then the INTELLO® PLUS glued onto the ORCON® CLASSIC bead.

Figure 10.72: : Use ORCON® CLASSIC to connect the INTELLO® PLUS to the concrete floor.

Figure 10.73: Horizontal battens for the service cavity


Figure 10.75: Dedicated skirting board mount timber and cable channel.
Photo courtesy of Blaise Building Services

Wall services cavity

Horizontally fixed battens point contact with the studs and lowers the overall thermal bridging (Figure 10.73). However, the plasterboard needs to run vertically which potentially leads to less efficient use of plasterboard lengths and more jointing work required. It also increases the risk of a visually uneven finish on long run walls with potential glancing light issues on the finish coat of the joints. Additional battens may be needed to fix the skirting boards and/or cornices as well. Plasterboard could still be run horizontally if non-typical batten spacing is used to align with plaster joints, skirtings and cornices.

Vertical batten configuration allows almost standard plasterboard installation. INTELLO® PLUS is held more securely, this is especially useful for blow-in insulation types. The plasterboard can be applied in the standard horizontal orientation fixed to the vertical battens as if it were a traditional stud wall (Figure 10.76). The fixing recommendations of the gypsum board manufacturer can be easily followed, and fewer plaster joints (less time) is required. This method allows the electrician to fit power outlets and light switches at the typical height (~300 mm) and light switches (~1000 mm) with typical metal mounting brackets. The ability to use long run plaster sheets means it may be easier to achieve smooth & flat finishes. The main drawback is that you will have slightly more thermal bridging compared to horizontal battens. In this configuration one needs to ensure the vertical battens stop short from the floor to allow cables or pipes to be run horizontally at or near floor level (Figure 10.74). It is also possible to plan for a dedicated cable channel behind the skirting board (Figure 10.75).

Using clever batten configurations, it is also possible to transition cables at strategic locations. As at inter-floor junctions (Figure 10.76).

When using services cavities, it is a good idea to specify rigid boards inserted behind power outlets outlets to ensure plasterboard saws do not damage the air barrier.

Figure 10.74: Vertical battens for the service cavity.
Photo courtesy of Michael Limb Builders

Figure 10.76: Creative battening allows for cable pathway.
Photo courtesy of Blaise Building Services

Figure 10.77: Ceiling battens fixed over structural members.
Photo courtesy of G-LUX Builders

Figure 10.79: Battens clamp INTELLO® PLUS with drop ceiling.
Photo courtesy of Huon Hemp House

Figure 10.81: Furring channel & clip over INTELLO® PLUS

Figure 10.83: Completed INTELLO® PLUS ceiling with furring channel and clip.
Photo courtesy of I-Smart Building Group

Ceiling services cavity

It is important to properly secure INTELLO® PLUS for insulation loading. INTELLO® PLUS should not be installed on rafters or trusses more than 1000 mm spacing.

Distance between the staples should be between 50 and 100 mm (blown insulation), lightweight batt type insulation materials the stapling distance may be 100 to 150 mm. The recommended fixing is timber battens perpendicular across the rafters or trusses with maximum 600 mm spacing. Batten thickness should be at least 35 mm nominal thickness.

Timber battens fixed perpendicular to the timber structure provide strongest support for the INTELLO® PLUS ceiling air barrier (Figure 10.77).

Batten depth is very important when using blown-in insulation as it is possible the weight can cause the INTELLO® PLUS to sag (Figure 10.78). If sagging occurs further than the batten height the plasterboard installation may be hindered. In addition, in the case of blown-in insulation and insulation materials with a high density (e.g. wood fiber insulation boards), an additional batten must be attached to the overlaps of transversely laid membranes. This is sufficient to hold R6.0 of damp blow in cellulose fibre (approx 10 kg/m² of weight). Alternatively, INTELLO® PLUS can be laid lengthwise to the rafters.

When using furring channel clips attached to ceiling battens, it is possible to achieve a decent sized service cavity to facilitate Heat Recovery Ventilation (HRV) ductwork (Figure 10.79) while maintaining a strong hold on the INTELLO® PLUS using the battens.

The feet clips can also be fixed directly to the INTELLO® PLUS and may be long enough to create enough room for HRV ductwork, but additional timber battens should be used to ensure the INTELLO® PLUS is adequately supported (Figure 10.80). Furring channel clips (Figure 10.81) should not be the primary support for the INTELLO® PLUS and insulation. Common practice in Australia is to use packaging strapping (Figure 10.82) to support the ceiling insulation prior to the INTELLO® PLUS being installed. In this case the packaging strap removes the load on the INTELLO® PLUS and it is suitable to use clips to hold the INTELLO® PLUS and create a service cavity (Figure 10.83).

Figure 10.78: Blown-in insulation.
Photo courtesy of Huon Hemp House

Figure 10.80: Metal feet brackets hold INTELLO® PLUS and provide rail mounting for drop ceiling.
Photo courtesy of Enduro Builders

Figure 10.82: Plastic packaging strap used to hold wall/ceiling insulation.
Photo courtesy of Eureka Insulation.

Figure 10.84: Adjustable furring channel clip with thread.
Photo courtesy of Pro Clima New Zealand

Figure 10.86: Battens perpendicular to structure.
Photo courtesy of Passive Builders.

Specialist screw mounting furring channel clips can provide a SOLID point fixing to timber structures. These are a good solution to allow furring channels to be used but no load should be placed onto the INTELLO® PLUS as these are only point fixings (Figure 10.83 & 10.84).
Innovative custom craft timber fixings are possible (Figure 10.85). These can be custom built for any depth and configuration of services. Close spacing will allow significant strength for holding the INTELLO® PLUS.
If service cavity battens are fixed perpendicular to the main structure it is possible to feed electrical cables over battens (Figure 10.86). Consideration needs to be made to the reduced fixing strength of the INTELLO® PLUS layer in this configuration.
If electrical cables are run above the INTELLO® PLUS in the insulated structure they will need to be sealed if routed through the INTELLO® PLUS layer (Figure 10.87). Flat cables can be well sealed using TESCON® tape. Running cables within the service cavity is preferable.
It is recommended to use surface mounted lighting when INTELLO® PLUS is used behind ceiling linings. If using downlights near INTELLO® PLUS only energy efficient, low wattage LEDs with IC-4 rating (AS/NZS 60598.2.2) should be used and also housed in downlight covers suitably sized and temperature rated at or above 90 °C temperature resistance.

Figure 10.85: Innovative craft solution for service cavity.
Photo courtesy of Ovens and Kings Builders

Figure 10.87: Sealing flat cables using TESCON® tapes.
Photo courtesy of The Burrow Farm

Figure 10.88: CONTEGA® PV connection to masonry.
Photo courtesy of Eclipse Passive House

Connecting into masonry
Render coats on masonry, straw bale, hemp or mud brick can be considered air barriers. To connect into these render layers, use CONTEGA® PV where the mesh can be embedded in the render for an airtight connection from the framed structure to the render (Figure 10.88).

Figure 10.89: KAFLEX applied before cable connections are made.
Photo courtesy of Blaise Building Services

Figure 10.91: ROFLEX installed before pipe connections are made.
Photo courtesy of Huon Hemp House

Internal penetrations

KAFLEX can be mounted over the cables and adhered if the protruding cable length is short (Figure 10.89 & 10.90). Pulling many meters of cable through a KAFLEX grommet may damage the grommet and other sealing approaches should be considered.

When using ROFLEX grommets the grommets must be placed over the pipes before the plumber continues with the plumbing connections (Figure 10.91). It will be quickly established that you cannot get the grommet onto the pipes otherwise. The adhesive flange or TESCON EXTORA® tape do not have to be adhered until the Blower Door verification stage.

Large pipe diameters are sealed with ROFLEX and TESCON® tape (Figure 10.92). The ROFLEX must be fitted before plumbing is completed and continuous. Otherwise, it is impossible to get the grommet on, and other sealing approaches will be needed. It is possible to seal around completed pipework with TESCON® products, but it will be more labour intensive compared to ROFLEX grommets. ROFLEX POST and TESCON EXTOSEAL® can also be used in difficult applications or for sealing air barrier after cables/pipes have already been installed.

Figure 10.90: Integrated adhesive flange.
Photo courtesy of Blaise Building Services

Figure 10.92: Larger ROFLEX grommets for large pipes.
Photo courtesy of Passive House Construction Products Victoria

Figure 10.93: INTELLO® PLUS laid such that overlaps not in vertice.
Photo courtesy of SL Insulation

Wall to ceiling junctions

Where the roof air barrier meets the wall air barrier connection should not be made in the corner (Figure 10.93). The connection needs to be made either on the flat wall section or flat roof, ideally 200-300 mm in from the vertices (Figure 10.94). Proper planning during installation is required to ensure the INTELLO® PLUS membrane is fully into the corner and will to not inhibit the battens.

Figure 10.94: Tape connection made on wall flat surface.
Photo courtesy of Blaise Building Services

Figure 10.95: Structural penetrations of INTELLO® PLUS.
Photo courtesy of Sticks_n_Bricks

Structural penetrations

Timber structural members penetrating the INTELLO® PLUS air barrier (Figure 10.95) are best sealed using TESCON® tapes and care and attention to detail application is required (Figure 10.96). For optimum airtightness outcomes these scenarios should be limited in the design phase of the project.

Figure 10.96: TESCON® VANA taping around structural elements.
Photo courtesy of Sticks_n_Bricks

Figure 10.97: INTELLO® PLUS before non-structural partitions.
Photo courtesy of Passive House Construction Products Victoria

Internal partitions

Non-structural internal partition walls can be assembled after the INTELLO® PLUS is installed. This allows continuity of the air barrier (Figure 10.97).
Allowing 50 mm gap between partitions and the structure means that the INTELLO® PLUS connections can still be made over the top of the partitions or even fed over the top after the partitions are installed (Figure 10.98).

Figure 10.98: Planning allows connections to be made later.
Photo courtesy of Michael Limb Builders

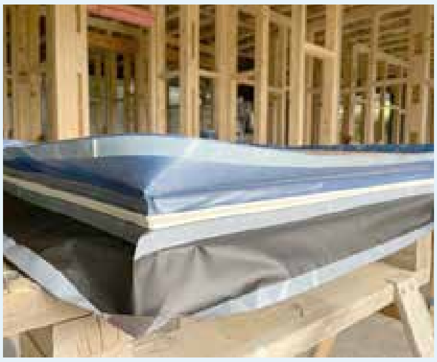


Figure 10.99: CONTEGA® IQ installed in combination with CONTEGA® EXO.
Photo courtesy of Compound

Window sealing

When installing windows, it is often easier to pre-plan the connections of the windows to the air barrier prior to installation of the windows. The CONTEGA® IQ is applied to the window prior to installation and may be used in conjunction with CONTEGA® EXO for the exterior WRB connection (Figure 10.99).
It some circumstances it may be difficult to tape into the window reveals particularly in small windows and therefore may be beneficial to make connections to the window before it is installed. Once installed the pre-prepared membrane can be easily connected to (Figure 10.100).

Figure 10.100: Pre-installed INTELLO® PLUS strip to window prior to install.
Photo courtesy of Ben Amor

Figure 10.101: Prefabricated systems with pre-installed INTELLO® PLUS.
Photo courtesy of Eclipse Passive House

Figure 10.103: Battens configuration designed into panels.
Photo courtesy of Carbonlite

Figure 10.105: Panel connections made on site.
Photo Courtesy of I-Smart Building Group

Factory planned

Factory built, prefabricated panels and modern methods of construction allow for membranes to be installed and quality controlled in factory environments (Figure 10.101 – 10.103). This allows a lot of the planning and problem-solving to be done prior to site works.

Service cavity planning (Figure 10.103) and window connections (Figure 10.102) are all taken care of in the factory.

Once on site the panel positioning and connections between panels are the main issues to be dealt with (Figure 10.104 & 10.105) with most of the difficult details.

Mass timber systems may have pre-installed SOLITEX ADHERO® to not only protect the timber on the journey from factory to site but also providing a long term durable WRB for weatherproofing (Figure 10.106). This is important for mass timber as it is sensitive to moisture and potential distortion. Ask your Cross-Laminated-Timber (CLT) supplier for SOLITEX ADHERO® to be used, the best quality highly durable membrane technology to protect the structure. The site finishing will include treatment of all end grains and joints in the CLT with pro clima TESCON EXTORA® tapes that come in 60 mm, 100 mm, 150 mm and 200 mm wide options.

INTELLO® PLUS is generally not required for mass timber systems that typically have timber exposed on the interior surface.

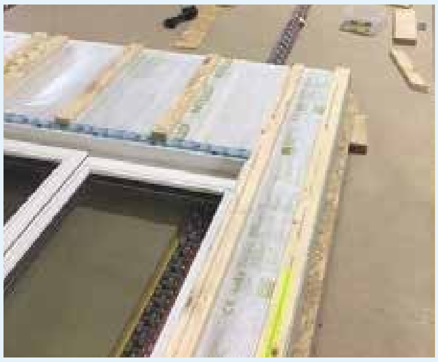


Figure 10.102: Windows installed in factory.
Photo courtesy of Eclipse Passive House

Figure 10.104: Panelised systems craned on site.
Photo courtesy of pro clima NZ

Figure 10.106: Mass timber with SOLITEX EXTASANA ADHERO®.
Photo courtesy of Yard Stix

10.4 Summary

- Resilient structures must have a high potential freedom from structural damage achieved by high drying capacity due to selection of class 4 vapour permeable weather resistive barriers in climate zones 2-8.
- Weather Resistive Barrier (WRB) membranes solutions must have a vapour diffusion resistance of less than 0.88 MNs/g for flexible membranes.
- When using a fully adhered membrane over a rigid board they must have a combined vapour diffusion resistance less than 7.0 MNs/g (class 3 permeable, AS/NZS 4200.1).
- TEEE membranes provide excellent UV stability and long-term thermal stability for highest durability.
- In the tropics, Climate Zone 1, SOLITEX ADHERO® over a rigid substrate allows for optimal weatherproofing and airtightness on the exterior side with ideal vapour resistance, as required in air-conditioned buildings in tropical environments.
- Humidity-variable diffusion resistance air barriers on the inside provide water vapour control to mitigate condensation and allow for additional inward drying capacity when needed.
- The high-performance Intelligent Air Barrier INTELLO® PLUS offers exceptionally high variability of diffusion resistance that is effective in any climate and thus provides unparalleled protection for thermally insulated walls and roofs in Australian Climate Zones 2 to 8.
- Planning of the services cavity allows for optimal airtightness outcomes with ease of buildability.
- Light coloured claddings reduce the temperature of external WRB layers and therefore may increase the risk of moisture related issue on the external side. Dark claddings increase the inward vapour drive and enhance the drying of the system in summer. Design is a balance between moisture and energy performance in summer and winter.
- "The higher the drying capability of a construction, the greater the moisture load events that it can tolerate and still remain free of mould and structural damage." (pro clima rule for safe constructions.)
- Buildings should be designed to dry and built dry through proper site works planning. High drying potential accounts for unforeseen moisture loads during operation.
- The use of foam type insulation will inhibit drying to the side of the construction in which it is placed. Bi-directional drying using vapour permeable and intelligent membranes allows for greatest drying potential.
- The pro clima tapes TESCON EXTORA®, SOLITEX ADHERO® and CONTEGA® EXO have a high water resistance due to the SOLID adhesive and guarantee a high durability even in rain and high humidity conditions.
- Additional peace of mind is given by pro clima system performance guarantee.
- The pro clima systems ensure ideal protection against decay, mildew, mould and corrosion and a healthy living environment.
- When designing WRB systems they should be continuous, facilitate drainage with a high degree of buildability. In the planning phase consideration needs to be given to:
  - drainage battens for walls and roofs
  - temporary fixing of membranes during the construction phase to prevent damage
  - sealing of penetrations and build sequencing for ROFLEX and KAFLEX
  - ventilation of wall cavities and design of inlet and outlet vents
  - connections of the WRB to the window frames (CONTEGA® EXO, TESCON EXTORA®, TESCON EXTORA® PROFIL) to create a continuous "system"
  - build sequencing of windows and WRB layers and how connections will be made
  - ventilation of the roof system and batten height
  - the connections and drainage of roofing membranes integrating to the wall systems
  - drainage of water and condensate from the WRB at eaves while allowing for inlet ventilation
  - roof ridge ventilation requirements with or without truss spaces
  - effects of counter batten height on valley tray height and detailing
  - the connection of upper storey wall membranes to the lower sections of roofing membranes.
- When designing INTELLO® PLUS IAB systems they should be continuous, well sealed and designed with a high degree of buildability. In the planning phase consideration needs to be given to:
  - INTELLO® conneX planning and execution
  - installation on timber or metal structures. Using DUPLEX where necessary.
  - difficult areas to seal such as dorma windows and TESCON® PROFIL
  - wall to floor connections using ORCON® CLASSIC and air barrier properties of flooring materials
  - service cavities and sequencing trades
  - ceiling service cavities and space required for ducts, pipes and cables
  - surface mounted lighting is recommended when using INTELLO® PLUS on ceilings.
  - IC-4 rated recessed downlights (AS/NZS 60598.2.2) may be used but must be housed in covers suitably sized and temperature rated at or above 90 °C temperature resistance.
  - options for ceiling batten fixing based on insulation type and dead weight loads
  - routing cables and keeping them within the service cavities
  - connections to other air barrier materials such as CONTEGA® PV to render layers
  - penetrations in the air barriers and build sequencing when using ROFLEX and KAFLEX
  - making effective connections at ceilings and walls
  - limiting structural penetrations of the air barriers where possible
  - non-load bearing partitions being installed after INTELLO® PLUS
  - window connection options (CONTEGA® IQ, TESCON® PROFIL or TESCON® VANA) based on window type and build sequencing

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Further information about application and construction can be found in the pro clima planning documentation online under products or resources.

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Notes

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