BULLETIN

ISSUE 604

VAPOUR CONTROL IN NEW ZEALAND BUILDINGS

December 2016

- BRANZ has examined the issue of vapour control in New Zealand buildings from a wide perspective.
- This bulletin gives some options for reducing the level of humidity in wall construction.
- The best ways to prevent condensation problems are to control moisture at source, adequately vent occupied spaces and minimise airflow to colder parts of the structure.

1.0 INTRODUCTION

1.0.1 In Bulletin 439 *Condensation risk in walls*, BRANZ said vapour barriers are not necessary to reduce condensation risk in walls and roof spaces in the vast majority of circumstances where traditional building methods are used.

1.0.2 This current bulletin provides advice on vapour control based on recent BRANZ experiments. It takes a wider perspective on vapour control beyond the question, “Do I need a vapour barrier?”

1.0.3 The research confirms that the absence of a specific vapour control layer in traditional New Zealand walls is unlikely to lead to significant accumulation of condensation in walls. Designers who wish to reduce the risk of mould growth or corrosion can specify a vapour control layer with a slightly higher vapour resistance than painted internal linings. Use of a complete vapour barrier such as polythene reduces a wall’s ability to dry to the inside and is not recommended.

1.0.4 The best ways to prevent condensation problems are to:

- control moisture generation at source
- adequately vent occupied spaces – 0.3–0.5 air changes per hour (ach)
- limit air movement into wall or roof assemblies.

2.0 WATER VAPOUR AND CONDENSATION

2.0.1 Water vapour is the gaseous form of water. In liquid form, individual water molecules cling together through a phenomenon known as hydrogen bonding. If enough heat energy is provided, the intermolecular bonds break, and individual molecules escape into their gaseous form.

2.0.2 The reverse is also true. When water vapour cools, hydrogen bonding begins – individual molecules bond together and form liquid water (condensation).

2.0.3 For any given temperature, there is a maximum amount of water vapour the air can hold, and the air then is saturated. More water vapour can be held in air at higher temperatures than lower temperatures. The term ‘relative humidity’, normally expressed as a percentage, describes how saturated the air is at a given temperature. 100% relative humidity means the air is saturated.

2.0.4 Relative humidity can be altered in two ways – changing the amount of water vapour in the mixture or changing the temperature.

2.0.5 Increasing temperature or removing water vapour lowers relative humidity. Lowering the temperature or adding water vapour increases relative humidity.

2.0.6 Keeping the amount of water vapour constant and cooling the mixture eventually brings the relative humidity to 100%. The temperature at which this occurs is the dew point temperature. The dew point temperature depends on the air temperature and amount of water vapour in the air.

2.0.7 As air and water vapour move through a structure, the mixture’s temperature will change and the amount of water vapour will change. If a surface has a lower temperature than the dew point of the air, condensation forms on the surface. For example, condensation forms on windows when the glass temperature is below the dew point temperature of the interior air.

2.1 WATER VAPOUR TRANSPORT

2.1.1 Water vapour moves through a structure mainly through diffusion and convection:

- Diffusion moves water vapour through a material from a high concentration (vapour pressure) to a low concentration.
- Convection carries water vapour by the bulk movement of air. This is typically a much faster and hence more dominant process than diffusion.

2.2 VAPOUR PERMEABILITY, PERMEANCE AND RESISTANCE

2.2.1 These terms relate to how easily water vapour can diffuse through a material.

- Permeability is a basic material property. Permeability represents the rate of vapour flow through a unit area of material with a unit thickness and unit vapour pressure difference. (The SI unit is kg/s.m.Pa but ng/s.m.Pa is often used.)
- Permeance relates to a particular thickness of material. Permeance (ng/s.m^2.Pa) = permeability/thickness.
- Vapour resistance is the reciprocal of permeance. The unit of vapour resistance used in documents referenced by the New Zealand Building Code is MNs/g (1 s.m^2.Pa/ng is equal to 1,000 MNs/g).

3.0 VAPOUR BARRIERS AND VAPOUR RETARDERS

3.0.1 A completely impermeable material has an effective permeance of zero. This is a vapour barrier. However, in New Zealand, the term vapour barrier is taken to mean polythene sheeting.

3.0.2 A more useful term is vapour retarder – most materials have a measurable vapour permeance and restrict the flow of water vapour. The International Code Council (ICC) International Residential Code classifies the following types of vapour retarder:

- Class I: ≤0.1 US perm (>175 MNs/g) – impermeable.
- Class II: >0.1 and ≤1.0 US perm (>17.5 and ≤175 MNs/g) – semi-impermeable.
- Class III: 1.0 to 10 US perm (>1.75 and ≤17.5 MNs/g) – semi-permeable.

3.0.3 In New Zealand, it is more common to talk about vapour resistance than vapour permeance. AS/NZS 4200:1994 *Pliable building membranes* *and underlays* has these classifications of vapour resistance:

- High: >450 MNs/g
- Medium: >7 and ≤450 MNs/g
- Low: <7 MNs/g.

3.0.4 Table 23 of New Zealand Building Code clause E2 *External moisture* Acceptable Solution E2/AS1 contains acceptable properties for roof and wall underlays. In general, a vapour resistance of ≤7 MNs/g (low resistance) is required when measured by ASTM E96/E96M-15 *Standard test methods for water vapor transmission of materials* – the wet cup test. For a damp-proof course or damp-proof membrane, resistance must be ≥90 MNs/g, roughly equivalent to a Class I vapour retarder.

3.0.5 A material's vapour resistance is not necessarily fixed. Many materials become more permeable as humidity increases. This is often desirable, because if liquid water is in the structure, the water vapour can diffuse out more easily. Natural wood products exhibit this property as do manufactured wood products to a lesser degree.

3.0.6 Smart vapour retarders (SVRs) offer changing vapour resistance. At high humidities, the vapour resistance drops to allow more water vapour through. The specific relationship between relative humidity and vapour resistance will be dependent on the type of SVR.

3.0.7 A vapour control layer is a component within the wall that controls water vapour diffusion. This avoids confusion between multiple terms such as 'vapour barrier', 'vapour retarder' and 'vapour check' (although those terms are used for specific recommendations).

3.0.8 An air control layer is a component designed to limit air movement through the structure. If detailed correctly, a vapour control layer will also act as an air control layer. However, an air control layer may or may not act as a vapour control layer, depending on its vapour resistance.

4.0 NEW ZEALAND RESIDENTIAL CONSTRUCTION AND WHOLE-HOUSE MOISTURE TRANSPORT

4.0.1 Typically, New Zealand walls are made of materials with a low vapour resistance. More water vapour will diffuse through such a wall than a wall with a higher vapour resistance. Even so, diffusion adds little to whole-house moisture transport. Convective processes move much more water vapour from a typical house (Figure 1). Convective processes such as air movement through open windows or exfiltration through cracks and gaps can move approximately 15 litres/day (L/day) of water vapour. Under peak conditions, diffusion only moves about 2 L/day.

4.0.2 Controlling moisture sources and airflows is the most effective way of dealing with indoor moisture.

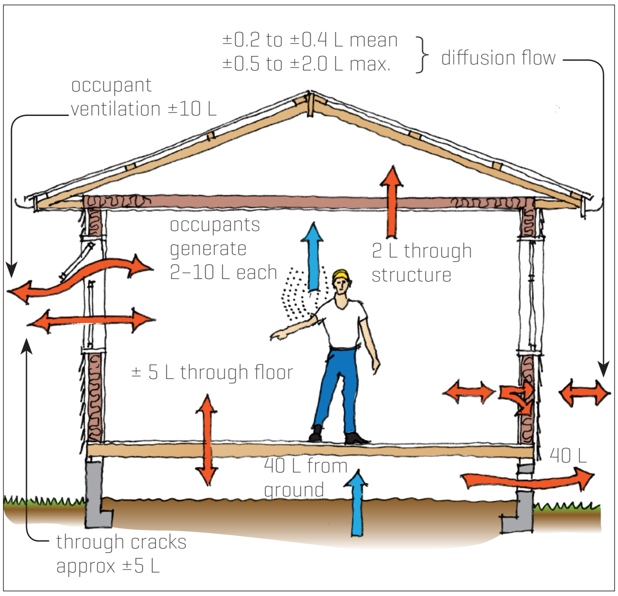

Figure 1. Approximate moisture generation (blue arrows) and moisture transport (red arrows) per day for a 100 m² house (adapted from Trethowen, 1987).

4.0.3 There are potential issues with wall layers that have low vapour resistance but significant thermal resistance, such as fibreglass or polyester insulation. Assume that the indoor space is warmer and has more water vapour in it. The vapour pressure will be higher indoors, so water vapour will try to diffuse from inside to outside. The temperature will be higher indoors and so heat will diffuse from inside to outside.

4.0.4 As the water vapour passes through the materials that make up the wall, its temperature will drop and so will the vapour pressure. In the absence of airflows, the temperature drop across each layer is dependent on its thermal resistance. Similarly, the vapour pressure drop across each layer is dependent on the vapour resistance provided by that layer.

4.0.5 If the insulation has a high thermal resistance and low vapour resistance, there will be a large temperature drop but only a small vapour pressure drop across it. The relative humidity of the air will therefore be higher outside the insulation, because the temperature has dropped and this has not been counterbalanced by a corresponding reduction in vapour pressure. Under certain conditions, the temperature of the water vapour will be less than the dew point temperature, and condensation will form at the underlay.

4.0.6 Damage from condensation in walls is rarely reported in New Zealand. However, one way of reducing the risk is to use a layer with a relatively high vapour resistance on the warm side of the insulation so the majority of the vapour pressure drop will occur across this layer. Although the temperature may be unaltered at the underlay, the vapour pressure will be lower, so relative humidity will be lower. This is the principle behind using materials such as polythene as vapour barriers.

4.0.7 The downsides of using a material with a very high vapour resistance (a vapour barrier) are that:

- it may be an unnecessary cost
- it potentially increases the condensation risk when the vapour pressure drive is reversed
- it reduces the ability for liquid water to dry from the structure to the interior.

4.0.8 The last point is probably the most important. Overseas, there is a focus on drying mechanisms rather than wetting-prevention mechanisms. Providing a structure with a means to recover (in this case, from condensation) is often more effective than trying to prevent condensation in the first place. The balance is found when there is enough vapour resistance to prevent condensation damage further into the wall while still providing good drying capacity. In many cases, sufficient vapour resistance is provided by painted linings.

5.0 OVERSEAS PRACTICE

5.0.1 The US Department of Energy's Building America programme has clarified the use of vapour control layers in the International Residential Code. In this model building code, the nature of the vapour control layer in a wall assembly depends on the local climate zone, as defined in the ICC International Energy Conservation Code. In general, the International Residential Code now allows a Class III vapour retarder – such as latex (acrylic) paint – in more locations than previously. Acrylic paint on wall lining is commonly used in New Zealand construction.

6.0 EXTERIOR CLIMATE

6.0.1 Table 1 classifies New Zealand's climate under International Energy Conservation Code (IECC) climate zones. The climate data used was generated by NIWA (2008) for use in the Energy Efficiency and Conservation Authority's (EECA's) Home Energy Rating Scheme (HERS). IECC zones use a number for the thermal aspect of the climate (zone 1 is extremely hot, zone 8 extremely cold) and a letter corresponding to moisture (A is moist, B is dry, C is marine).

Table 1. IECC climate classification based on HERS climates.

LOCATION	IECC CLIMATE CLASSIFICATION
Auckland	3C
Christchurch	4A
Dunedin	4C
Hokitika	4A
Kaitaia	3C
Lauder	5C
Napier	3C
Nelson	3C
New Plymouth	3C
Queenstown	5A
Tauranga	3C

6.0.2 All the New Zealand locations are either moist or marine, with thermal criteria of 3 to 5. Queenstown and Lauder just fall into the colder zone 5.

6.0.3 Table R702.7.1 of the International Residential Code shows the situations where a Class III vapour retarder can be used. The table can be accessed via the PublicAccess section of the ICC website at http://codes.iccsafe.org/I-Codes.html. Note that the R-values in the code are in imperial units.

6.0.4 Based on Table 1 climate classifications, New Zealand's approach to vapour control is in line with the current International Residential Code. For the New Zealand climate and common cladding configurations, painted interior linings provide enough vapour resistance to prevent condensation damage.

7.0 INDOOR CLIMATE

7.0.1 There is no recognised standard indoor climate for New Zealand homes. Overseas standards give guidance, but it is unknown how representative these are for New Zealand. The BRANZ approach was to use a modified version of the intermediate method in ASHRAE 160-2009 *Criteria for moisture-control design analysis in buildings*.

7.0.2 In this method, the indoor humidity is a function of the 24-hour running-average outdoor vapour pressure and the moisture generation and ventilation rates inside the building. The humidity has an upper cut-off at 70%, but in this analysis, that cut-off was removed, so indoor relative humidity could exceed 70%.

7.0.3 The indoor temperature is a function of the 24-hour running-average outdoor temperature, the heating set point and the indoor temperature shift (the indoor/outdoor temperature difference without any purchased heat). In ASHRAE 160, the set point is 18.3°C and the temperature shift 2.8°C. This implies the indoor temperature never goes below 18.3°C – unrealistic for New Zealand, where heating often varies from room to room.

7.0.4 With no agreed temperature and humidity profile for New Zealand, the heating set point of 16°C was chosen with a temperature shift of 3°C. Other parameters assumed were an air change rate of 0.5 ach, a building volume of 450 m^3 and a moisture generation rate of 1.16×10^{-4} kg/s (10 L/day), corresponding to a 3-bedroom house in ASHRAE 160.

8.0 BRANZ RESEARCH

8.0.1 BRANZ studied wall configurations in a test building (Study Report 344 *Vapour control in New Zealand walls*). The intent was to use the measured data from these walls to benchmark computer simulations of the wall types. The computer simulations could then be used to predict how similar walls would behave under different climatic conditions. WUFI Pro V5.3 software was used.

8.0.2 The experiment looked at timber-framed and steel-framed walls with a range of insulation and underlay configurations. The effect of a smart vapour retarder was also investigated.

8.0.3 This bulletin looks at how a typical wall – painted plasterboard internal lining, fibreglass insulation, a flexible wall underlay and a cladding over a cavity – behaved in Queenstown under various parameters. The research showed that the behaviour is reasonably similar over different climates, as might be expected, given the data in section 6.0.

8.0.4 Two aspects of wall performance are considered:
- Moisture accumulation – whether condensation occurs and builds up over time. In the results, this is termed 'excess moisture' – the amount of water in the material beyond the 'free saturation' level.
- Relative humidity – whether this is high compared with specified criteria.

8.1 MOISTURE ACCUMULATION

8.1.1 In the WUFI simulations, the water content in the outer 5 mm of the insulation was used as an estimate of the amount of condensation in the wall. The study looked at different parameters to see which are likely to start causing condensation to accumulate. The parameters are:
- increasing insulation R-values (R1.8, R2.8, R4.4)
- lowering external temperature (shifts of 2.5°C, 5°C and 7°C)
- increasing underlay vapour resistance (from 0.25 MNS/g to 7 MNS/g, the maximum that E2/AS1 permits)
- lowering the indoor ventilation rate (0.5, 0.4, 0.3, 0.2, 0.1 ach)
- increasing the moisture generation rate (from a 3-bedroom house as the baseline).

8.2 R-VALUE CHANGE AND TEMPERATURE SHIFTS

8.2.1 In all cases, no moisture is predicted to accumulate over time. A tiny amount of transient moisture is predicted with the default climate for the R2.8 and R4.4 walls. This suggests that simply increasing the R-value of the insulation by a moderate amount will not cause excessive condensation in the wall.

8.3 VAPOUR RESISTANCE OF UNDERLAY

8.3.1 The wall with R2.8 insulation had its underlay altered so that the vapour resistance was at the maximum level stated in Table 23 of E2/AS1 (7 MNs/g). In the initial analysis, the underlay had a vapour resistance of 0.25 MNs/g. Figure 2 shows that moisture is more likely to accumulate with an underlay at the limit of the E2/AS1 permissible values of vapour resistance, all other things being equal.

8.4 INDOOR VENTILATION RATE

8.4.1 The wall with R2.8 insulation was subjected to indoor climates with a range of ventilation rates. A 2.5°C temperature shift downwards was applied to the climate to represent a more severe winter than the typical data.

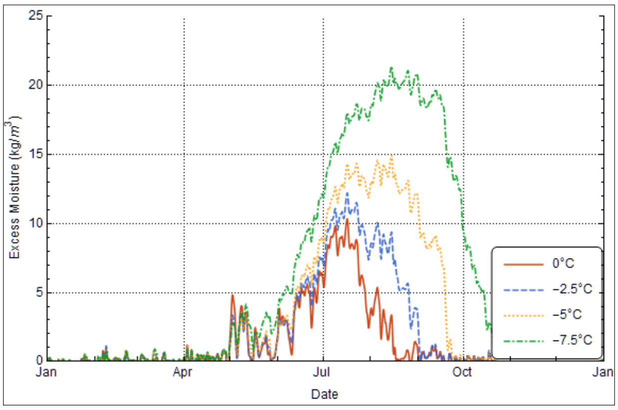

Figure 2. Excess moisture in outer 5 mm of insulation – effect of temperature shift on a 90 mm framed wall with R2.8 insulation and an underlay with a vapour resistance of 7 MNs/g.

8.4.2 Figure 3 shows the effect of varying the ventilation rate from 0.5 ach down to 0.1 ach. Once the ventilation rate goes below 0.3 ach, the indoor relative humidity increases rapidly to the point that, at 0.1 ach, it rarely drops below 90%. This leads to significant moisture accumulation in the 0.2 ach and 0.1 ach cases.

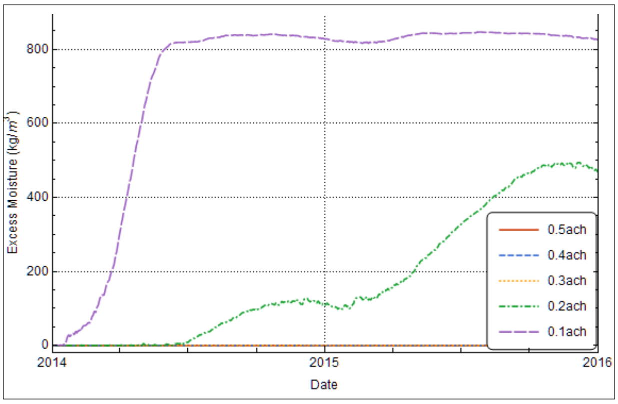

Figure 3. Excess moisture in outer 5 mm of insulation – effect of room ventilation rate on 90 mm framed wall with R2.8 insulation.

8.5 MOISTURE GENERATION RATE

8.5.1 The base indoor climate used in this analysis had a moisture generation rate that corresponded to a 3-bedroom house. In conjunction with an indoor ventilation rate of 0.5 ach and an exterior climate with a 2.5°C temperature shift downwards, the moisture generation rates examined were:
- 3 bedrooms (1.16×10^{-4} kg/s or 10.0 L/day)
- 5 bedrooms (1.39×10^{-4} kg/s or 12.0 L/day)
- 5 bedrooms with jetted tub without exhaust fan (1.54×10^{-4} kg/s or 13.3 L/day)
- 2×10^{-4} kg/s (or 17.3 L/day).

8.5.2 Figure 4 shows that excess moisture is only frequently predicted in the case where the moisture generation rate was 2×10^{-4} kg/s. This moisture generation rate is far in excess of the design value for a 5-bedroom house with a jetted tub without exhaust fan.

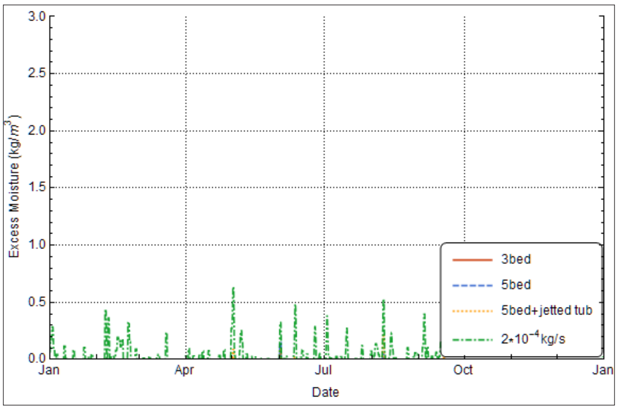

Figure 4. Excess moisture in outer 5 mm of insulation – effect of moisture generation rate on 90 mm framed wall with R2.8 insulation.

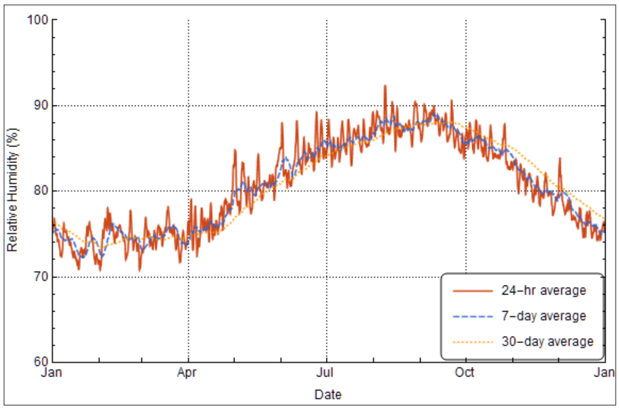

Figure 5. Relative humidity at the underlay for a typical wall in Queenstown and different running averages.

8.6 KEY POINTS ON MOISTURE ACCUMULATION

8.6.1 Moisture accumulation is the criterion traditionally used to assess condensation risk in New Zealand.

8.6.2 This study suggests that the biggest factor in creating a moisture accumulation problem is a lack of room ventilation, followed by having a high resistance underlay. In this analysis, the increase in vapour resistance of the underlay was done in isolation – thermal properties were unaltered. Other factors, including increased insulation, climate change and moisture generation, had little effect on moisture accumulation over the range of parameters.

8.7 RELATIVE HUMIDITY

8.7.1 Although accumulation of condensation is one of the traditional ways to assess whether a wall has satisfactory performance, it is not the only criterion. Accumulation relates to liquid moisture, but high humidity within structures can support mould growth and corrosion/decay without condensation occurring. For this reason, ASHRAE 160 has a series of failure criteria relating to different averaging periods for the relative humidity on any surface. Specifically, the:

- 24-hour average should not reach 100% (removed in a later addendum to the standard)
- 7-day average should not exceed 98% (removed in a later addendum to the standard)
- 30-day average should not exceed 80%.

8.7.2 The third criterion is specifically aimed at preventing mould growth and corrosion. ASHRAE 160 states that mould-resistant materials may be able to resist higher surface relative humidities and that other criteria as specified by the manufacturer may be used.

8.7.3 Figure 5 shows the study wall meets the first two ASHRAE criteria but fails the third. The 30-day running average relative humidity exceeds 80% for a significant portion of time. There is debate as to how much weight should be placed on the 80% relative humidity criteria since it does not appear to align particularly well with real damage within walls.

8.7.4 One way to lower the humidity at the underlay is to use layers with a higher vapour resistance inboard of the insulation. Figure 6 shows this being done with a smart vapour retarder (SVR) as a vapour control layer. With the SVR in place, the 30-day average relative humidity stays below 80%. However, this solution would not work in all geographical locations. To get the humidity under 80% in other locations may require a higher vapour resistance for the control layer, which reintroduces the potential issues of using vapour barriers.

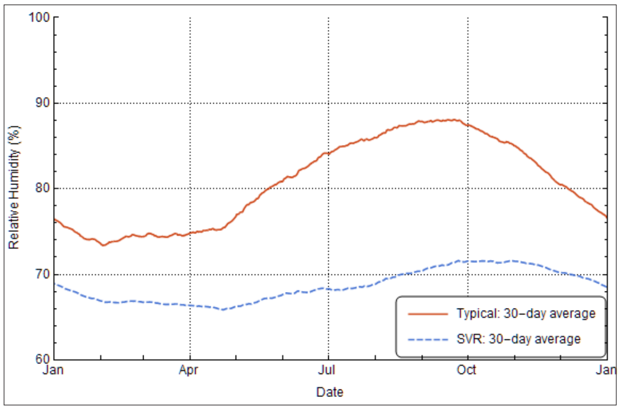

Figure 6. Using an SVR to lower the humidity at the underlay for a typical wall in Queenstown.

8.7.5 With insufficient evidence of the 30-day average long-term relative humidity causing damage in New Zealand homes, BRANZ does not recommend that use of an SVR becomes mandatory. Nevertheless, there are several benefits arising from their use and no evidence they will do harm.

9.0 ROOF MOISTURE

9.0.1 Condensation problems are more commonly observed in roofs than walls, for three main reasons:

- Moist indoor air tends to be transported to the roof space, especially when the ceiling is not airtight.
- Roofs normally get colder than walls at night because they face the sky.
- The underside of the roof is visible when looking into the roof space whereas it is not so easy to look into walls.

9.0.2 BRANZ is continuing research into roof moisture and ventilation, but in general, the same principles apply as with walls:

- reduce moisture generation
- ventilate the occupied space to reduce indoor humidity
- limit airflow to colder parts of the structure, like the roof space.

9.0.3 Roof ventilation (airflow above the insulation and below the cladding/underlay) can also help avoid condensation. Traditionally, roofs were ventilated simply by the way they were constructed. Today's roofs tend to be more airtight, so ventilation provisions may be necessary for certain roof types, such as skillion roofs. Vapour control layers may also be necessary with specific types of roof construction. Research is still active in this area at BRANZ.

10.0 SUMMARY

10.0.1 BRANZ research confirms that New Zealand's traditional approach to vapour control (painted interior linings) is unlikely to cause accumulation of moisture within walls. New Zealand practice is also now in line with the recommendations in the International Residential Code, which are based on climate zones.

10.0.2 The research indicates that, although accumulation of condensation is unlikely, the relative humidity, particularly at the wall underlay, may be high enough to support mould growth. However, the criterion looked at here, specifically the 30-day running average humidity being less than 80%, does not align well with field experience of damage.

10.0.3 Designers who wish to lower the humidity at the underlay can specify a layer with a slightly higher vapour resistance on the warm side of the insulation, such as a smart vapour retarder, which still allows drying. Avoid using a vapour barrier such as polythene, because this reduces a wall's ability to dry in the event of a leak.

10.0.4 More specific advice depends on a building's interior and exterior climate and construction. However, BRANZ research shows that the best way to prevent condensation is to adequately vent the occupied space. If ventilation levels drop below 0.3 ach, indoor humidity is likely to get very high, leading to problems throughout the structure.

11.0 RESOURCES AND REFERENCES

MBIE

- New Zealand Building Code clause E2 *External moisture* Acceptable Solution E2/AS1

BRANZ

- Bulletin 439 *Condensation risk in walls* (withdrawn)
- Study Report 344 *Vapour control in New Zealand walls*

CODES AND STANDARDS

- AS/NZS 4200:1994 *Pliable building membranes and underlays.*
- ASTM E96/E96M-15 *Standard test methods for water vapor transmission of materials.*
- ANSI/ASHRAE Standard 160-2009: *Criteria for moisture-control design analysis in buildings*.
- ICC 2015 *International Residential Code*. Available from http://codes.iccsafe.org/I-Codes.html
- ICC 2015 *International Energy Conservation Code*. Available from http://codes.iccsafe.org/I-Codes.html

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ISSN 1170-8395