Reducing Condensation in the Roof Space

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Abstract

With increasing pressures on governments to save energy, the construction industry has been looking at the design of buildings and designing them to become more energy efficient. This has led to increased air tightness and greater thermal insulation thicknesses to reduce energy usage. However, these advances in energy efficiency have led to more problems of condensation within buildings, and designers are becoming increasingly aware of such risks.

This paper intends to look at how condensation occurs and its risk, the means of reducing and assessing the risk, and how advances in membrane technology have allowed designers and specifiers to reduce this risk to acceptable limits.

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REDUCING CONDENSATION IN THE ROOF SPACE

GENERAL

When designing any type of building, the designers must take into consideration heat, air movement, and moisture. The external conditions must be considered on a project-by-project basis, based on the particular climate in which the development is to take place. The local climate will have a deciding factor on the design; for example, a building in the U.S. will be subject to very different climates from that in the North.

The internal climates of buildings should also be looked at closely before specifying particular constructions. The intended use of these buildings and potential changes of use throughout the lifespan of the building will have an effect on a number of factors within the building fabric. Means of ventilation within the building and air movement should also be considered.

All of the above points must be viewed together and not in isolation before correct specifications of building can take place.

What is Condensation?

To be able to design a building to reduce risks of condensation, the designer first should have a good understanding of what condensation is. The air's ability to hold or contain moisture is dependent on the air temperature. As the temperature increases, so the ability for air to hold vapor is increased. Similarly, as the air temperature reduces, the air's ability to hold vapor also reduces. Once the air has reached the temperature at which it cannot hold more vapor, the saturation point is reached. This is called the dew point. After this point, any vapor generated will be deposited in the form of condensation.

Therefore, condensation can be produced by either an increase in vapor or a decrease in the air's temperature. A common example of condensation is in the bathroom where warm, vapor-laden air passes over the mirror. Here, the air's temperature is lower and its ability to hold vapor is reduced, hence condensation is formed on the cold surface. Therefore, internal air temperatures and relative humidities and vapor pressures have a determining effect on the risk of condensation within buildings.

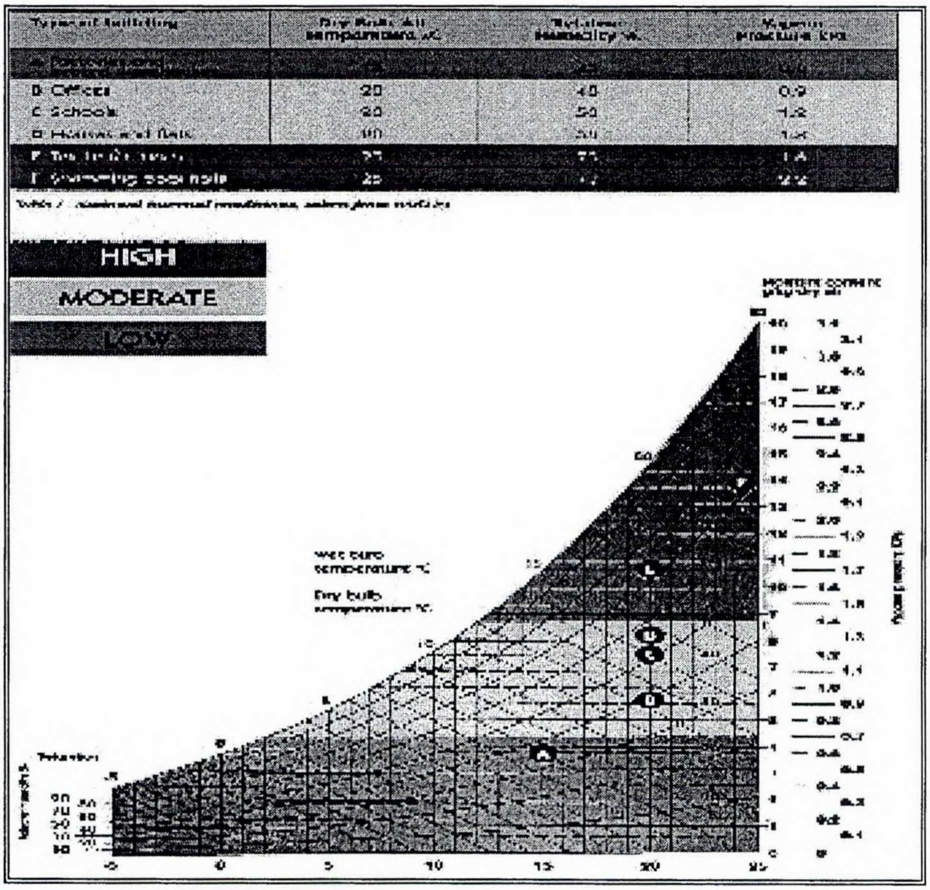

Figure 1: The psychometric chart, color-coded to show risk of condensation within a variety of buildings.

Building Use

The usage of buildings will differ from type to type. Heated warehouses, for example, can be considered as low-risk buildings, as the humidity and temperatures are generally low in these types of buildings. Offices, schools, and houses would be considered moderate risk, as the internal temperature and relative humidity is increased. A typical household, for example, can generate between 7 and 14 liters of water each day just from breathing, cooking, washing, and drying clothes. High-risk buildings, such as textile factories or swimming pools, will generate

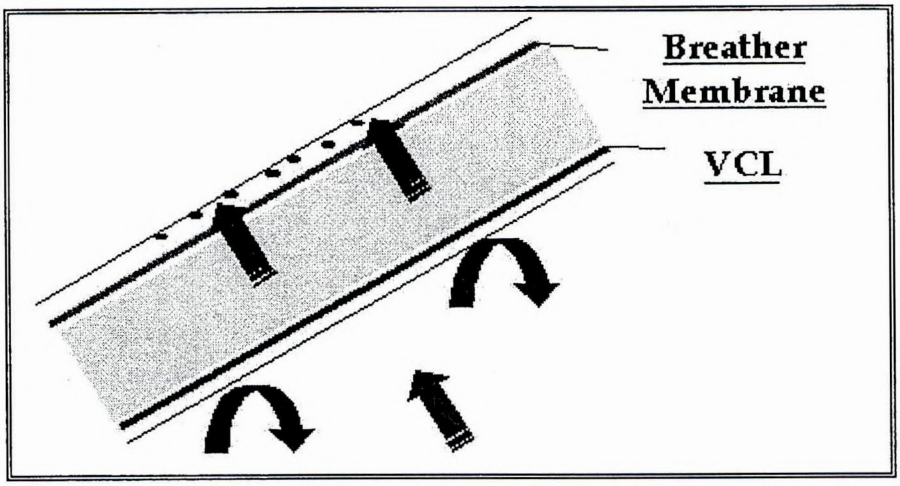

Figure 2—The vapor drive through a typical, built-up metal roofing system.

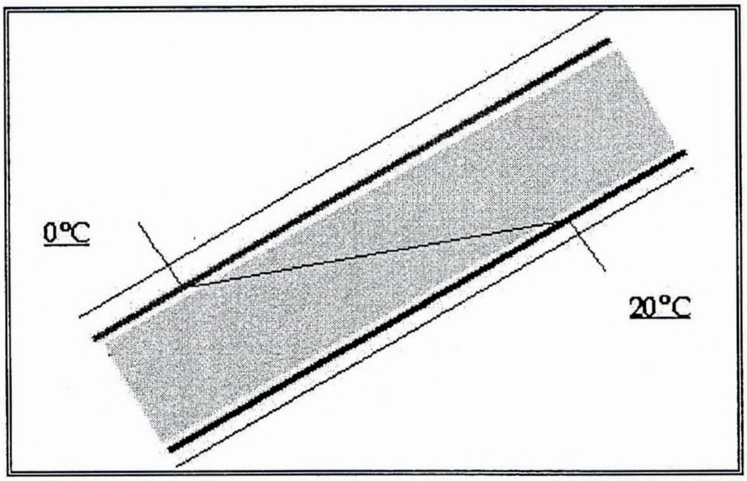

Figure 3—The dramatic temperature differential within a built-up metal roofing system.

a lot of vapor with increased temperatures and increased relative humidity.

As vapor generation differs from building to building, the amount of vapor within that building increases the vapor pressure. Generally, in winter months in colder climates, the humidity outside will be less; therefore, the vapor pressure drive will be from inside to out. As building design for air leakage has increased through the years, the easy passage for this vapor through chimneys, draughty glazing units, etc. is reduced. This vapor, therefore, is driven through the building structure. A second point to consider, due to increases in energy efficiency, is that this building structure now has increased thermal insulation; therefore, a sharp temperature drop can be evident through a relatively small thickness of insulation. This quick temperature drop can create problems of condensation.

Figure 1 shows the psychometric chart color coded to show risk of condensation within a variety of buildings.

Figure 2 shows the vapor drive through a typical, built-up metal roofing system

Figure 3 shows the dramatic temperature differential within a built up metal system roof.

Night Sky Radiation

When considering condensation in metal roofing systems, the effects of night sky radiation should be taken into consideration. On a clear night, the cooling effect on the outer sheet by low external air temperatures is intensified by radiant heat losses from the roof surface. The clear sky acts as a large heat sink which draws radiated energy from those surfaces which face it. This heat radiation to the sky can result in super cooling where the roof is cooled by direct heat losses and by radiant heat losses. Systems with very little thermal mass will be more prone to this form of heat loss.

The super cooling can lead to surface temperatures lower than the temperature of the external air. This can lead to temperatures between 5° C and 10°C below the external air temperature. In these circumstances, the risk of condensation is increased dramatically.

Types of Condensation

There are a number of types of condensation. The main forms of condensation are:-

- Surface Condensation, where vapor condenses on cold surfaces. This is generally easily identified and can be dealt with quickly.
- Interstitial Condensation is condensation within the building fabric and can create a number of effects. Here, the vapor is cooled to its dew point with water droplets forming within the structure.

- Reverse Condensation, sometimes called summer condensation, occurs when the vapor pressure is not from inside to out, but is reversed and the vapor condenses on the internal, cool surfaces

Effects of Condensation

The various forms of condensation discussed can have a variety of effects on a building and its contents. Timber rot, as well as swelling and distortion of timber, can become evident. In metal frame constructions, this can lead to rust and corrosion.

Any moisture generation within insulation can and will affect the thermal performance of insulations, depending on their properties. Mold growth, damage to decorations and electric wiring, as well as items within the loft, can also occur due to condensation problems.

Reducing Condensation

Having considered the risks of condensation and its effects, effective ways of reducing condensation will be considered.

There are a variety of measures which can be taken to reduce the risks.

1. The internal vapor pressure can be reduced. This may be in the form of mechanical ventilation or simply opening windows and doors, therefore allowing the vapor to escape freely and harmlessly.
2. Provide a continuous barrier to stop the vapor entering the building fabric. Building elements with a high vapor resistance can stop vapor from entering areas where condensation can occur (e.g., a vapor control layer). A complete seal can be difficult; hence the reference to a vapor barrier has ceased and vapor retarders are now referred to.
3. Promote the release of moisture above the insulation. Permeable, diffusion open materials are utilized to allow vapor to escape before it reaches it dew point temperature.

Membranes Which Will Reduce the Condensation Risk

In this paper we will consider two forms of membranes which can help to reduce the risk of condensation.

1. Breather Membranes, which help promote the release of vapor
2. Vapor Control Layers, which reduce the amount of vapor entering the building fabric.

The breather membrane, by its design, will not allow the passage of liquid through it; it will, however, allow moisture in the form of vapor to pass through it.

A vapor control layer will not allow either vapor as a liquid or as vapor to pass through it.

Breather Membrane

As discussed, a breather membrane will allow vapor, but not liquid, to pass through. Typically, a breather membrane will be used on the cold side of the insulation and will allow the vapor to pass through and safely condense on the external cold surface. Once the moisture has condensed into liquid form onto the breather membrane, it can no longer penetrate the structure and will drain appropriately.

Typical materials would be polypropylene spunbond or spunbond polyethylene. The perm value is very important to consider when looking at a variety of breather membranes and the higher value should be chosen, especially in higher-risk forms of construction.

The breather membrane is a secondary waterproofing protection and should be designed to provide some temporary cover during construction. It should not, however, be designed as the primary waterproofing cover. It must be installed behind the external weathering face and must be continuous and able to shed water out of the building. It must have a high perm value. Some breather membranes do suffer from the "tent effect." The membrane, if it is fully supported or touched from the underside, may allow moisture in liquid form to penetrate through. This must be con-

Figure 4—An example of three-layer, breathable membrane for use in roof and wall applications.

sidered when designing a structure and detailing a breather membrane.

Earlier forms of breathable membranes were micro-perforated polyethylene sheets. However, as technology has advanced, non-woven polyolefin membranes have been introduced to provide increased breathability and water resistance. These membranes have increased in technical specification and can offer UV resistance, fire resistance, water resistance, and increased perm values. *Figure 4* gives an example of a three-layer, breathable membrane for use in roof and wall applications.

Vapor Control Layers

Vapor Control Layers are commonplace in some form in the majority of buildings. Typical loose-laid vapor control layers are manufactured from polyethylene and aluminum.

In these situations, the vapor control layer requires a low perm value to resist the passage of vapor. Typically, this material will be installed on the warm side of the construction in northern climes. As well as specifying a vapor control layer with a low perm value, the membrane must be installed correctly, it must be continuous, treated with respect during installation, sealed at all laps to reduce convection, and sealed to other elements within the construction.

CASE STUDIES

In order to understand the important roles that breathable membranes can play in reducing the risk of condensation, two cold-pitched roof case studies will now be examined. These are cases where the insulation is placed horizontally at ceiling level with a loft space above. It is important to note that the case studies were of Scottish construction, where softwood sarking boards were used on top of the rafters and the primary waterproof covering was diffusion open (i.e., allowed the escape of vapor). Asphalt shingles, for example, are likely to have too much vapor resistance to allow the breather membrane to perform its function to its fullest potential.

Cold pitched roofs are commonplace in the UK and represent approximately 90% of the pitched roofing domestic market. Ventilation is provided at eaves and ridge level to allow the escape of vapor and the drying out of the timbers. However, with increased thermal insulation requirements, this has led to problems of condensation where the ventilation has not been installed correctly. A typical example would be where the insulation is laid tight at the eaves covering up the ventilation air gap and a non breathable underlay is used. This has resulted in condensation problems of timber rot and decreased insulation values.

Also, the air movement within the loft does provide lower thermal insulation and the risk of freezing pipes.

Due to improved technologies in breather membrane manufacture as previously discussed, and the high breathability figure that membranes now possess, research was undertaken to assess whether the breathability of the underlay alone could provide enough air movement to reduce the risk of condensation to such levels that ventilation was no longer required. The theory was that in these circumstances the whole roof could breathe and the system would not be reliant on individual air gaps below the underlay.

Case Study 1 – Stormont Lodge, Blairgowrie, Perthshire, Scotland

The first case study was of a nursing home where an extra story was to be added on top of the existing building. This building was specifically picked for research purposes as relatively high temperatures and relative humidities would be experienced at all times. Eight bedrooms were to be constructed, all en-suite. No vapor retarder was used at ceiling level. The use of softwood sarking boards would reduce the effect of the breathable membrane.

This research was taken over 18 months and was in conjunction with the Building Research Establishment, an independent research body.

Sensors were installed to measure:

1. External air temperature and relative humidity

2. External surface temperature

3. Temperature and relative humidity directly below the breather membrane

4. Internal surface temperature

5. Roof void air temperature and relative humidity.

Data loggers were used to store this information and took readings every 30 minutes. Every six weeks the information was downloaded onto a computer. At this time, moisture contents—both in the sarking boards and the timber rafters—were taken and tabulated. *Figure 5* shows a graph illustrating the moisture content levels through the test period.

As can be seen, the moisture contents increased in the winter; however, the roof dried out considerably in the summer. At no point did the moisture contents increase over 20%, which is deemed to be the critical moisture content level when considering potential rot or mold growth.

The independent BRE Summary concluded that the moisture contents of this non-ventilated, cold-pitched roof were similar to that found in conventionally ventilated roofs.

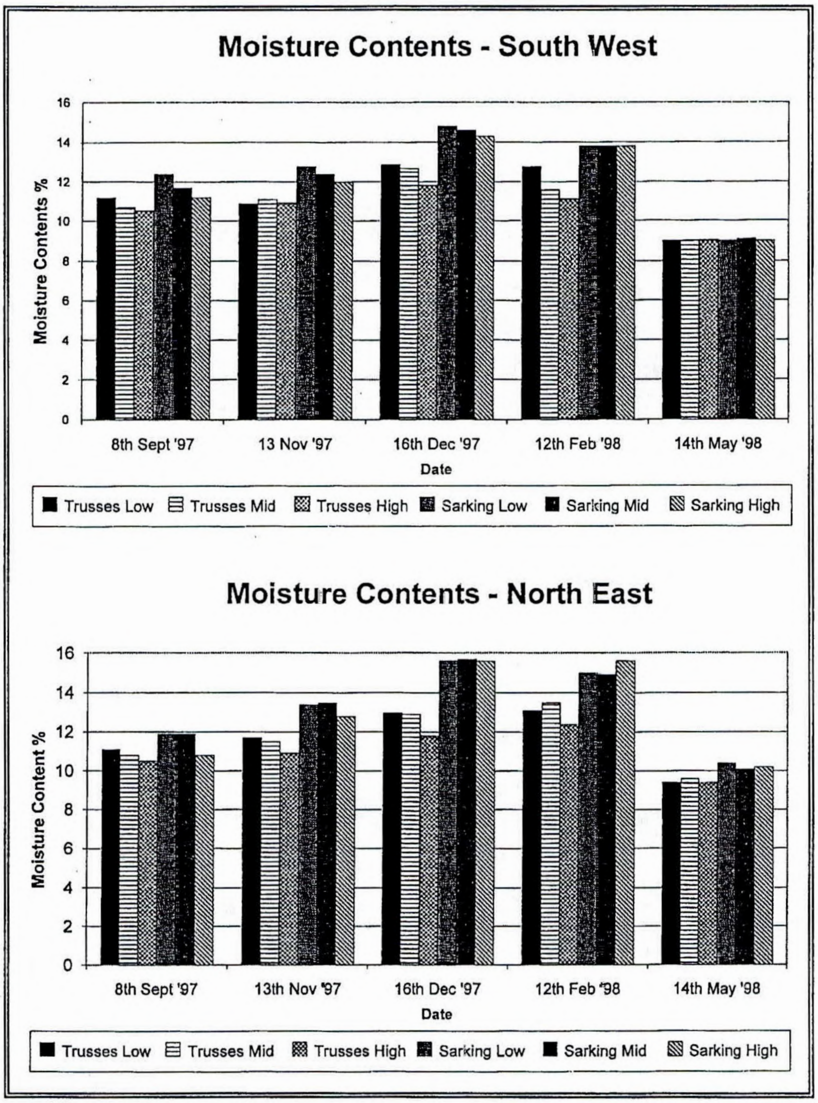

Figure 5—These graphs illustrate the moisture content levels through the test period.

Case Study 2 – Numerous Roofs in the Aberdeenshire Area

Test Sample

To further prove the performance of breathable underlays in cold pitched roofs, six projects were chosen at random and with the permission of the property owners. Five of the projects were houses, with one hotel included. The projects were as follows:

- Braeside Cottage—a cold, slated "traditional" ventilated roof
- Arnwell Farmhouse—a warm, slated roof, non-ventilated
- Beech Brae—a cold, unventilated roof
- Garbheinn House—a cold, ventilated roof. Two situations, one with Roofshield, the other one with traditional 1F felt.
- Rockstone Cottage—a cold non-ventilated roof
- Simpson's Hotel—a warm, non-ventilated roof

All of the above projects had close-boarded, softwood sarking.

These roofs varied in construction methods from a cold, unused loft space to a room in the roof, to a warm roof above a hotel. For comparative results, a traditionally ventilated roof was also inspected.

As can be seen, the roofs were of different shapes. One was a hotel and the rest were domestic. Some were cold roof with the insulation placed at ceiling level and some were warm roofs with the insulation placed in between the rafters. Where applicable, a vapor control layer was used.

At all the test locations, the internal and external humidities were taken along with internal and external temperatures.

Performance Criteria

The moisture content readings were the most relevant performance criteria in this study. It is generally accepted that moisture contents above 20% can lead to potential problems and certainly readings over 26% will lead to timber rot problems. Therefore, in this study, moisture contents of 20% or below were deemed to be satisfactory and within acceptable limits.

ANALYSIS OF TEST RESULTS

Of the non-ventilated roofs, the moisture contents were all below the previously discussed 20% moisture content. Sarking boards showed slight increases in moisture content compared to moisture content of rafters. This can be explained due to the increased moisture content of sarking boards as they are installed. Investigations of two timber merchants discovered that they feel that moisture contents will be an average between 25% and 30% moisture content and can be higher when delivered to site and stored outside, as is traditional with sarking boards. As the rafters and trusses are usually kiln-dried timber, these moisture contents are likely to be below 20% when initially installed.

The Garbheinn House gave an opportunity to analyze a cold ventilated roof using a breather membrane and a cold ventilated roof using the Type 1F felt. The moisture contents in both sections of these roofs were below 20%, and, therefore, satisfactory. It is interesting, however, to note that in the same position—i.e., low on the roof with the ventilated roof with Type 1F felt—the moisture contents were slightly higher. Also, it was interesting to note that the moisture content increased both on the sarking board and the rafters as the moisture content meter was taken nearer to the vents. This may be explained by humid air externally being ventilated into the loft, thereby increasing the moisture content at this point.

As a comparison, Braeside Cottage was utilized as it was on the Arnwell estate to analyze the difference between a non-ventilated roof and a ventilated roof. This cottage was nearly 100 years old. Slate vents have been installed at low and mid levels to provide through ventilation as a Type 1F felt was used. The moisture contents of the timber were consistently higher that any other moisture contents found on the day of testing in any other project. Through ventilation on the coomb ceilings was debatable as to whether 50mm clear air space was kept here. The moisture content found in some of the original sarking boards was at a level that would cause concern.

The lowest moisture contents found on that day was at Simpson's Hotel in Aberdeen. The moisture content of the sarking board was below 10%, as was the moisture content in the rafters. This was a non-ventilated, warm-pitched roof with polystyrene placed between the rafters. A foil-backed plasterboard was utilized horizontally at ceiling level; however, there were a number of penetrations evident and a number of down lighters used. Given that no specialist sealing of hatches or around any penetrations was observed, these moisture contents were very encouraging. Indeed, of all the projects, no special sealing of any gaps on the ceiling or the hatches was evident.

Conclusion of Case Study 2

In the test sample, the results have shown that the use of a breathable membrane has helped to keep moisture contents in these buildings at acceptable levels in non-ventilated, pitched roofs. All roofs are performing satisfactorily with moisture contents in the sarking board slightly higher than in the rafters, as is expected due to the different constraints on the supply of the timber to the building.

No appreciable difference in moisture content between those projects using ventilation and those which were not ventilated was shown. Indeed, in some areas, the moisture contents were higher (in the ventilated projects) and may actually have contributed to higher moisture contents. The test sample in terms of moisture content would be consistent with previous work carried out by the Building Research Establishment and results in terms of moisture contents in rafters and sarking are very similar as those encountered in these previous studies.

FURTHER RESEARCH

As can be seen from this report, a lot of research has gone into the use of breathable membranes and vapor control layers and how, with this new membrane technology, the risk of condensation can be reduced and allow specifiers flexibility of design.

The benefits of membranes can no longer be in any doubt; however, further research and technical papers are still in progress to further enhance knowledge of their benefits.

One such research project is through the British Board of Agreement, which follows three-dimensional condensation risk analysis of pitched roofs in a variety of situations. In this research, the roof shape can be taken into consideration, showing hips, valleys, dormers, ridges, etc. Each cell within one roof is approximately 1m x 1m and each cell is individually assessed for its condensation risk. This will further enhance a condensation risk analysis rather than a snapshot through a construction. A number of factors will be taken into consideration, including airflow, form of construction, capillarity, insulation values, etc. This research is at the forefront of condensation risk analysis and will further help analyze pitched roofs.

A new European Standard is currently being written. This is PR EN 13859-1, Underlay for Discontinuous Roofing. This takes into consideration the new technologies for breathable membranes and sets performance criteria for these new membranes.

British Standards

Annexes to BS 5534 Part 1, Slating & Tiling Code of Practice, are currently being written. They take into consideration the new benefits of these breathable membranes and how their benefits can be used in insulated, pitched roofs, giving a list of criteria and points to consider when specifying different types of underlays.

CONCLUSION

This paper has looked at a variety of matters that should be considered when assessing the condensation risk in roofs.

It has examined the principles of condensation, how condensation can be reduced, and advances in membrane technology to help reduce this risk of condensation. The two case studies give examples of roofs' performance utilizing this new membrane technology. With a clear understanding of the membrane's performance criteria, correct installation, and detailing, specifiers, designers, and consultants can utilize these new technologies to the benefit of all, while ensuring moisture in the roof space is kept to a minimum.