

# REDUCING CONDENSATION IN THE ROOF SPACE

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## INTRODUCTION

With increasing pressures on governments to save energy, the construction industry has been designing buildings to become more energy efficient. This has led to greater air tightness and increased thermal insulation thicknesses. However, these advances in energy efficiency can lead to problems of condensation within buildings if the vapor generation, dewpoint, positioning of the insulation, and vapor escape are not considered simultaneously.

This paper examines the risk of condensation, how it occurs, the means of assessing and mitigating condensation risk, and how advances in membrane technology have allowed designers and specifiers to reduce this risk to acceptable limits.

## General

With 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 Florida will be subject to very different climates from that in mid Canada.

The internal climates of buildings should also be reviewed 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?

In order to design a building to reduce the risks of condensation, the designer first should have a good understanding of the nature of condensation. 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, its ability to hold vapor also reduces.

Type of building	Dry Bulb Air Temperature °C	Relative Humidity %	Vapour Pressure kPa
A Factories and heated warehouses	15	35	0.6
B Offices	20	40	0.9
C Schools	20	50	1.2
D Houses and flats	20	55	1.3
E Textile factories	20	70	1.6
F Swimming pool halls	25	70	2.2

Table 1 - Notional internal conditions, taken from BS6229

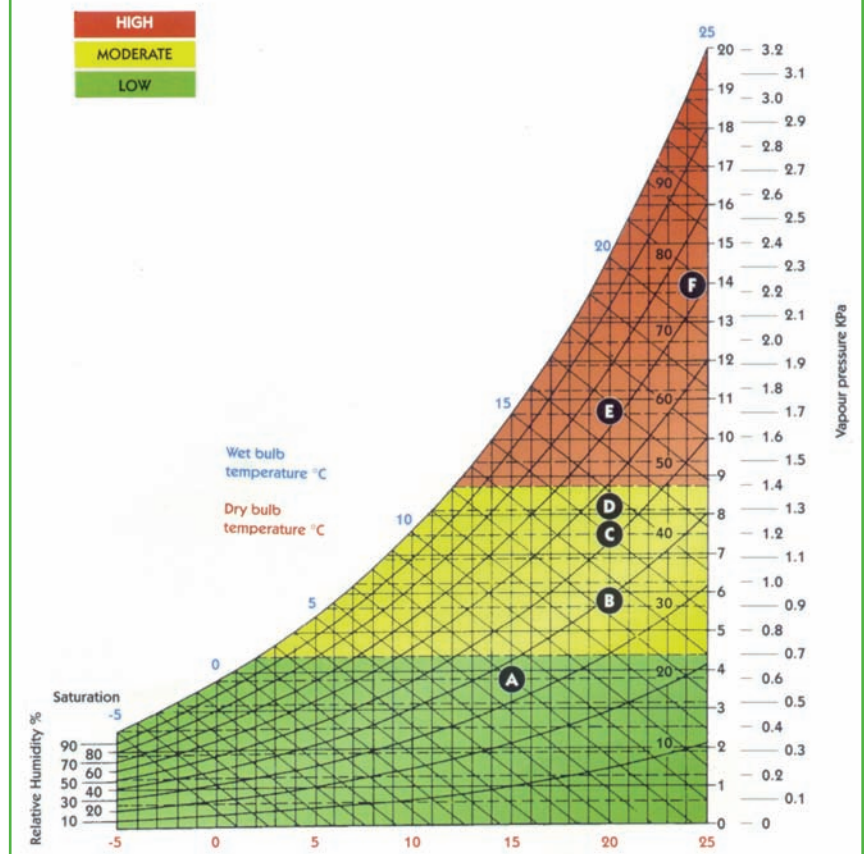
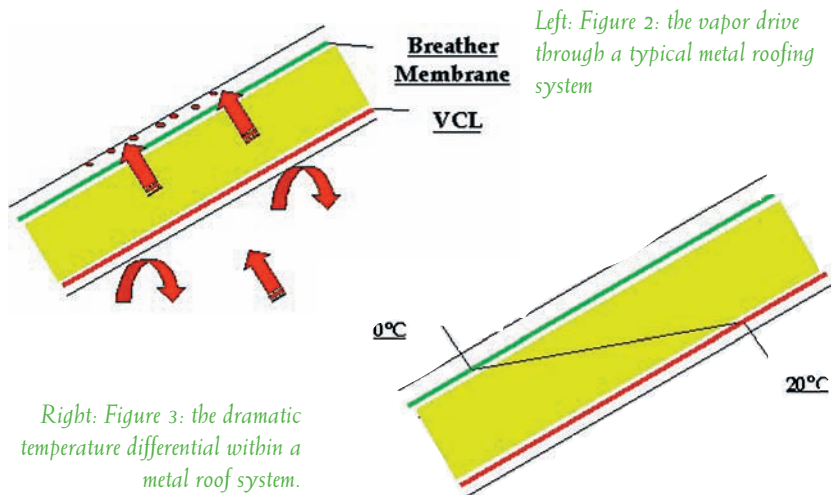


Figure 1: the psychrometric chart color coded to show risk of condensation within a variety of buildings.



Left: Figure 2: the vapor drive through a typical metal roofing system

Right: Figure 3: the dramatic temperature differential within a metal roof system.

## 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 that face it. This heat radiation to the sky can result in super cooling whereby 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 between 5° C and 10° C below the outside air temperature. In these circumstances, the risk of condensation is increased dramatically.

Once the air has reached the temperature at which it can hold no more moisture, the saturation point is reached. This is called the dew point. After this point, any further moisture will be deposited in the form of condensation.

Therefore, condensation can be produced by either an increase in humidity or a decrease in the air's temperature. A common example of condensation is in the bathroom where warm, moisture-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, relative humidities, and vapor pressures have a determining effect on the risk of condensation within buildings.

## Building Use

Heated warehouses can be considered as low-risk buildings, as the humidity and temperatures are generally low. Offices, schools, and houses would be considered moderate risk, as the internal temperature and relative humidity are 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 a considerable amount 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 developed through the years, the easy passage for this vapor through chimneys, drafty glazing units, etc. is reduced. This vapor 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. Insulation of the wrong surface without correct ventilation can create condensation problems.

Figure 1 shows the psychrometric chart color coded to show risk of condensation within a variety of buildings. Figure 2 shows the vapor drive through a typical metal roofing system. Figure 3 shows the dramatic temperature differential across a metal roof system.

## Types of Condensation

There are several types of condensation. The main forms of condensation are:

- **Surface Condensation**, where vapor condenses on cold surfaces. This is easily identified and dealt with.
- **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 near outer surfaces of the structure.
- **Reverse Condensation**, sometimes called summer condensation, occurs when the vapor pressure is not from inside to out; rather it 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 construction, this can lead to rust and corrosion.

Any moisture generation within insulation can and will affect the thermal performance. Mold growth and damage to furnishings, electric wiring, and items within the attic can also occur due to condensation problems.

## Reducing Condensation

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

A variety of measures may 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, thereby allowing the vapor to escape freely.
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 referenced.
3. **Promote the release of moisture above the insulation.** Permeable, diffusion-open materials (i.e., allowing the

escape of vapor) are utilized to allow vapor to escape before it reaches its dew point temperature.

## Membranes That Will Reduce the Condensation Risk

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

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

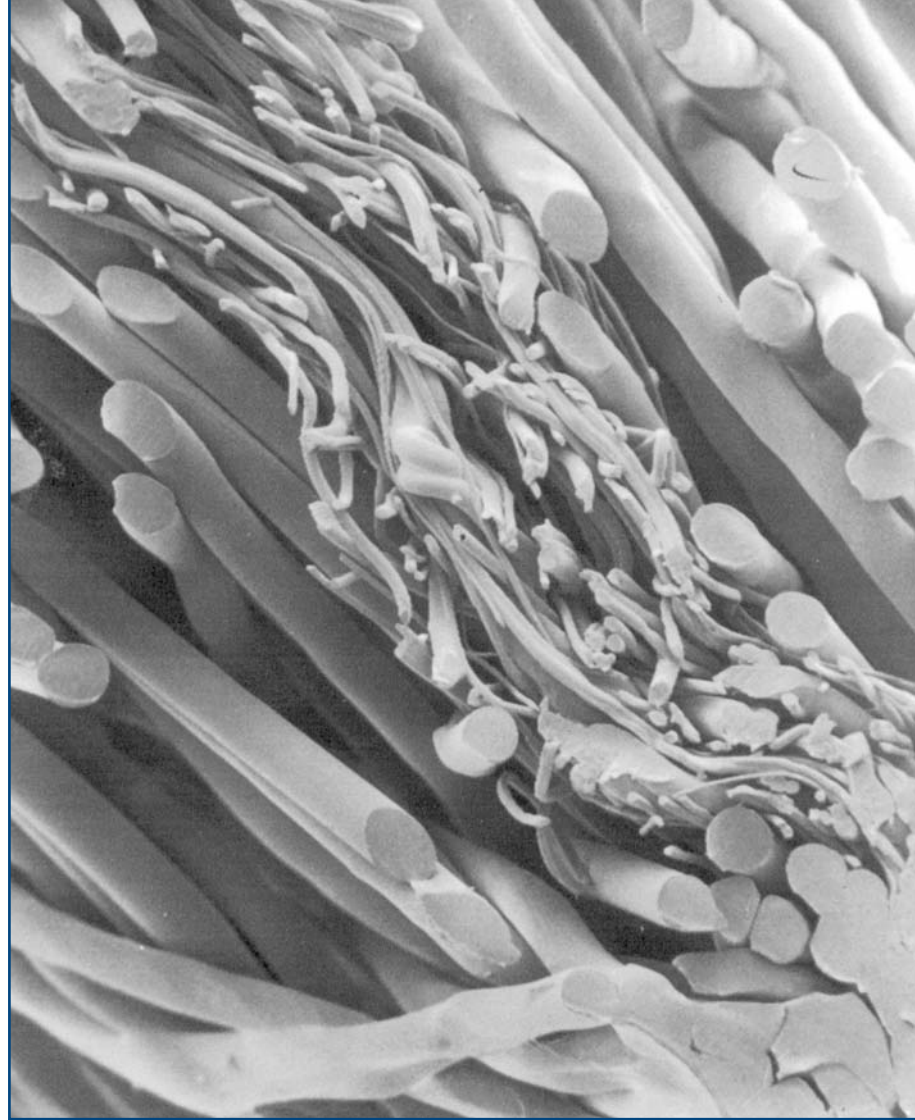
The breather membrane, by its design, will not allow the passage of liquid; it will, however, allow moisture in the form of vapor to pass through it. A vapor control permits neither vapor nor liquid to pass through.

### 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 spunbonded polypropylene or spunbonded polyethylene. The perm value is very important to consider when examining breather membranes. The higher value should be chosen, especially in higher risk forms of construction.

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



*Figure 4 gives an example of a three-layer, breathable membrane for use in roof and wall applications.*

be considered when designing a structure and detailing a breather membrane.

Earlier forms of breathable membranes were micro-perforated polyethylene sheets. However, as technology has advanced,



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non-woven polyolefin membranes have been introduced to provide increased breathability and water resistance. These membranes have improved performance and can offer UV resistance, fire resistance, water resistance, and increased perm values. *Figure 4* depicts 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 an attic space above. It is important to note that the case studies were of Scottish construction, where softwood sarking (spaced sheathing) 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 roof domestic market. Ventilation is provided at eaves and ridge level to allow the escape of vapor and the drying out of the timbers. Increased thermal insulation requirements, however, have 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 problems of timber rot and decreased insulation values. Also, the air movement within the attic does provide lower thermal insulation and the risk of freezing pipes.

Due to improved technologies in breather membrane manufacture, 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 ordinary 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 airgaps 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 com-

paratively high temperatures and relative humidities would be experienced at all times. Eight bedrooms were to be constructed *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 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 collected 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 collected 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 content 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 those found in conventionally ventilated roofs.

## 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**—cold, slated, “traditional” ventilated roof.
- **Arnwell Farmhouse**—warm, slated, non-ventilated roof.
- **Beech Brae**—cold, unventilated roof.
- **Garbhenn 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 warm roof above a hotel. For comparative results, a traditionally ventilated roof was also inspected.

As can be seen, the roofs were of different configurations. One was a hotel, and the rest were residential. Some were cold roofs 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 recorded along with internal and external temperatures.

## Performance Criteria

The moisture content readings were the most relevant 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.

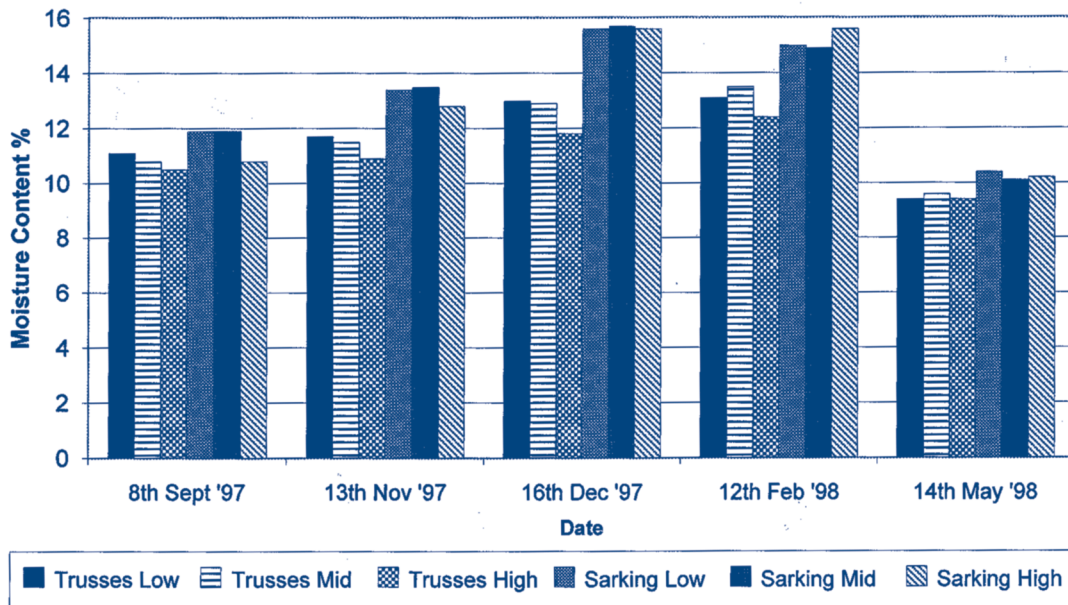
## ANALYSIS OF TEST RESULTS

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 the rafters. This can be explained due to the increased moisture content of sarking boards as they are installed. Investigations of two timber merchants concluded that moisture contents will be between 25% and 30% moisture content and can be higher when delivered to the site and stored outside, as is customary 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 presented 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 were therefore satisfactory.

It is interesting to note that in the same position—i.e., low on the roof in the ventilated roof having type 1F felt—the moisture contents were slightly higher. Also, it was noteworthy that the moisture content increased both on the sarking board and the rafters as the moisture 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.

## Moisture Contents - North East



## Moisture Contents - South West

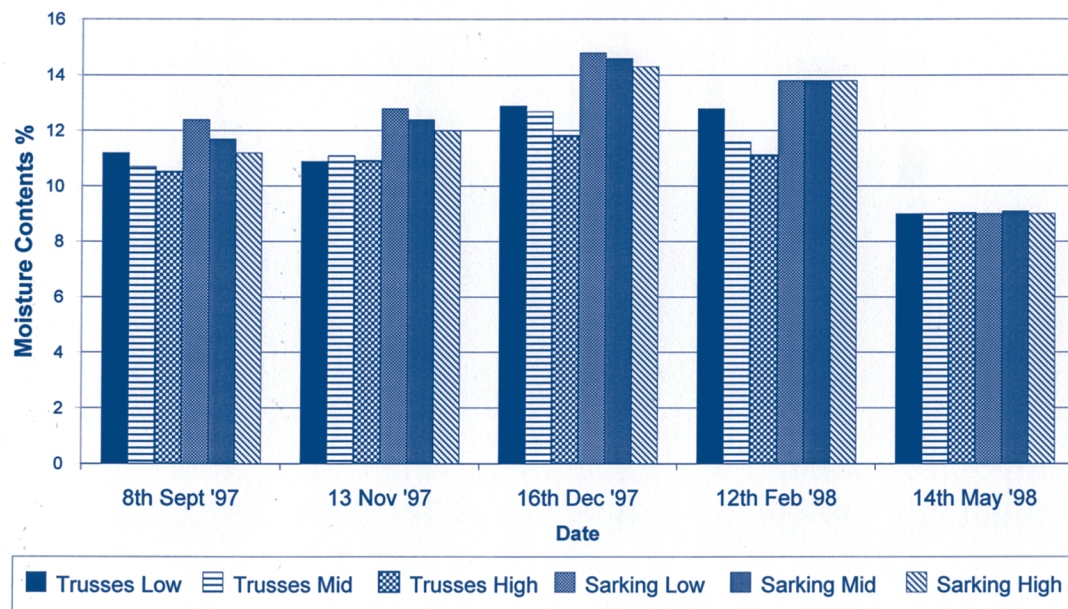


Figure 5—These graphs illustrate the moisture content levels through the test period.

As a comparison, Braeside Cottage and the Arnwell estate were used to distinguish between a non-ventilated roof and a ventilated roof. Braeside 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 than 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 (2 inches) 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 content 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 numerous penetrations evident and a number of down lighters used.

Given that no special 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 that were not ventilated was shown. Indeed, in some areas, the moisture contents were higher in the ventilated projects. The test sample in terms of moisture content would be consistent with previous work carried out by the Building Research Establishment, and moisture contents in rafters and sarking are very similar to those encountered in these previous studies.

## Further Research

As can be seen from this report, considerable research has gone into the use of breathable membranes and vapor control layers. With this new membrane technology, the risk of condensation can be reduced, allowing specifiers flexibility of design.

The benefits of breather membranes should now be evident; however, further research is in progress to 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 represent 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 benefits of these breathable membranes and their use in insulated, pitched roofs, giving a list of criteria and points to consider when specifying different types of underlays.

## CONCLUSION

This paper has examined 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 case studies give examples of roof 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. ■

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## ABOUT THE AUTHOR

**Iain Fairnington, BSc**, is a graduate of Napier University. He holds a Higher National Diploma in Building and has an Honors Degree in Building Engineering and Management. Since graduation, Fairnington has been employed with the A. Proctor Group in Perthshire, Scotland, as a technical manager. He is involved in research and development of breather membrane applications through an association with the Building Research Establishment and the British Board of Agreement. He sits on two British Standard committees, including BS 542 WG/3—Insulated Pitched Roofs, and BS 542 WG/6—Underlays for Slating and Tiling. Fairnington also sits on the European Standard Committee EN/TC 254/WG9—Underlays. He is an incorporated member of the Chartered Institute of Building.



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