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The Performance of Roofing Systems With and Without Underlay

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Preface

This work is intended for manufacturers of roofing products, researchers, and those involved in the technical aspects of building design.

Acknowledgments

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KEYWORDS

Roofs, Claddings, Underlays, Building Papers, Weatherproofing, Thermal Insulation, Condensation.

ABSTRACT

The performance of roofing systems with and without underlay has been investigated. Four aspects of roof system performance were investigated, viz. condensation under conditions of night-sky radiation, solar driven moisture transfer, the degradation of thermal insulation value due to wind penetration of insulation, and weather penetration.

The presence of building paper was found to increase the amount of condensation appearing on the cladding under conditions of night-sky radiation, contrary to conventional wisdom. However, the levels of condensation observed with underlay, although higher numerically, were not sufficient to cause drip off the cladding and onto the underlay, so in practice these higher levels of condensation are probably not important.

Solar-driven moisture transfer was found not to be a problem.

Literature searches and calculation suggested that loss in roof thermal insulation value due to wind penetration into roofing insulation, more likely if the roofing system has no underlay, was not highly significant.

Calculations indicated that underlays improve the weather penetration performance of concrete tile roofs, improve a little the performance of metal tile roofs, and do not improve the performance of long-run galvanised or precoated steel roofs. Whether this improvement is significant, how much improvement occurs, and for what roof geometries and weather conditions, cannot be accurately determined by the approximate methods used. More definitive results await experimental studies now commencing.

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INTRODUCTION

Underlays are a traditional component in roofing systems; their function and performance, however, are largely a matter of opinion and conjecture. Little quantitative work has been carried out to ascertain whether underlays actually perform in the ways presumed. They are presumed to perform the following functions:

1. **Air barrier to prevent rain penetration**

   The underlay is presumed to act as a relatively air-impermeable layer behind the roof cladding. When wind blows over the roof most of the air pressure difference created between the outdoors and the roof cavity is presumed to appear across the underlay, particularly in the case of unitised roof claddings (tiles, shakes, etc.) This would imply that there is little instantaneous air pressure difference across the roof cladding, thus preventing the wind from driving moisture through gaps in the cladding and into the roof space.

2. **Condensation protection**

   Traditional building trade wisdom says that when conditions are such that condensation would form on the roof cladding, this condensation occurs instead on the underlay or is dripped onto the underlay from the cladding. The absorbent underlay is able to hold the condensation until conditions change and the moisture can harmlessly evaporate away.

3. **Maintenance of insulation value**

   It is conjectured that roofs without underlay have larger air currents in the roof space, and that these currents are sufficient to diminish the insulation value of the roofing system, either through wind penetration of the roof insulation, or enhancement of convective heat transfer above the insulant.

4. **Solar driven moisture prevention**

   Some roofing underlays, e.g. fibre reinforced cement products, shakes, perhaps concrete tiles, are known to be susceptible to solar-driven moisture transfer. In this mechanism, rain is absorbed by the cladding, later to be driven into the roof space by heat from the sun. This mechanism is known to be modified by the presence of an underlay, but detailed studies would be required to quantify this modification.

This study examines each of these mechanisms in turn to establish their size and true nature. In phase I of the study, reported here, condensation due to night-sky radiation, and solar-driven moisture transfer are examined experimentally. Weather penetration and wind penetration of insulation are examined by literature survey and calculation.

In phase II of the study, carried out from June 1994 to June 1995, weather penetration was examined experimentally.

Night Sky Radiation and Condensation

Introduction

It is believed that one of the functions of underlays is to act as a buffer to condensation under conditions of significant night sky radiation. On frosty nights, heat radiates away from roof claddings to the cold night sky, cooling the cladding below the dew-point of the surrounding air. This causes condensation on the underside of the roof cladding. It is believed that if too much condensation collects, it will drip into the roof cavity, damaging ceiling linings or even timber structural members and undermining the insulation value of any insulant present.

The function of roofing underlays such as building paper in this case is to collect any dripping condensation and hold it until conditions are warmer, at which stage it can evaporate and be ventilated harmlessly away.

The size of this effect, and how it differs according to roof construction, has not been investigated. Whether certain roof claddings have a greater need for building paper than others or indeed whether some roofs need no building paper at all, at least to handle this mechanism, is unknown.

To investigate this effect thoroughly requires more than qualitative information that condensation is present; a complete understanding can only be gained if the amount and rate of change of condensation can be quantified. However, it appears that no attempts have ever been made to quantify the amount of condensation present in a roof structure. This section describes how condensation quantification was achieved and the results obtained using this technique.

Method

Roof space conditions

To examine experimentally the phenomenon of cladding condensation under conditions of night-sky radiation, it is necessary first to have a good understanding of the conditions that the roof will be exposed to.

The roof-space air psychrometric conditions are set in principle by the mixing of two air streams, indoor and outdoor, both finding their way into the roof cavity. In practice, it has been found that for the types of roofs under investigation, air leakage from the outside dominates over air leakage from the living space (Cunningham et al, 1994); consequently the roof-space air moisture conditions will be nearly identical to the external air moisture conditions.

Furthermore, for the roof types under investigation, the conventional picture of a gradient of air conditions from indoors to outdoors is unlikely to be correct because it has been shown

(Cunningham et al, 1994) that outside air has easy access to the space between any building paper and the roof cladding, via the eaves and between any gaps in the cladding. The conventional picture of a flow of moisture from indoors to the roof space, through the building paper and out through the cladding is unlikely to be correct. The true picture is more likely to be that there is a small movement of moist air into the roof space from indoors, which is entrained by much larger air flows entering the roof space from outdoors, with the combined air streams being ventilated out through gaps and cracks. It follows that air conditions near the cladding are dominated by external air finding its way into the outer cavities of the roof construction.

Physical structure of rig

A rig was designed based on the assumption that the roof-space air moisture conditions are very close to the external air moisture conditions. A $1m^2$ specimen of the roof under investigation is placed on a slope between two controlled climate chambers (see Figure 1). In the field, the roof cladding temperature at night is determined by the amount of heat radiating away to the sky, or during day-time is determined by the extra heat gained due to solar radiation. This effective outdoor temperature, EOT, can be calculated and is the temperature set in the top chamber. The bottom chamber simulates the roof-space air and, for reasons explained above, is maintained at the external air temperature and relative humidity conditions. An air pressure difference is established between the chambers, allowing the bottom chamber air to leak through gaps in the roof structure (the edges of the specimen and any gaps in the roof cladding) and out through the top, simulating natural ventilation through the roof.

Gravimetric measurement of condensation

Each specimen has a removable section cut out of the roof cladding - a square of approximately 200 mm on each side for metal claddings, or a cylinder of approximately 65 mm diameter for concrete tiles. The metal cladding square was gasketed to ensure that the roof maintained its integrity when the square was in place. The concrete tile cylinder was slightly tapered and was thus self-sealing when in place. Where the specimen contained building paper, a removable square of building paper was used, located immediately below the removable roof cladding section. The building paper square was held in place with magnetic strips along its edges.

Once an hour, the cladding and building paper squares were removed and weighed; in this way the amount of moisture or condensation accumulating in them could be quantified. To ensure that any condensation present on and in the removable sections was not disturbed, the weighing was done with the minimum of movement of the squares. The roof cladding sections had light rod attachments placed in them so that the section could be lifted a few millimetres, and hooked into the standard attachment of a balance set up to allow under-pan weighing. The building paper square was dropped a few millimetres onto a light stand placed on the pan of a balance and weighed.

Instrumentation

The roof specimens were instrumented principally so that dewpoints at various locations could be calculated. This required relative humidity and temperature sensors present at each location of interest. Figure 2 shows the location of these pairs.

Climate conditions

Each specimen was subjected to 34 hours of a simulated climate, during which hourly weighings of the removable building paper and cladding sections were taken, while temperatures and relative humidities were measured every five minutes.

The actual climate data used is graphed in Figure 3. It is based on a lightly smoothed version of a typical Auckland winter's day, specifically 6 July 1973, as taken from the Climdata database (Leslie and Trethowen, 1977). Shown also in Figure 3 is the dewpoint of the external air, which is simulated in the bottom chamber. It can be seen that the effective outdoor temperature, EOT, is below the dewpoint of the external air for 15 hours. Whether this results in condensation on the roof cladding or building paper depends on the thermal and hygroscopic properties of the cladding and of the building paper if present.

Results

Condensation accumulation

Table 1 shows the measured peak condensation (calculated as an area density, g/m^2) and integrated condensation (sum of condensation density × time) accumulated in each specimen type.

Specimen type	Peak cladding condensation g/m^2	Peak building paper condensation g/m^2	Cladding condensation × time $g\ hr/m^2$	Building paper condensation × time $g\ hr/m^2$
Long-run pre-coated steel without building paper	176	-	1921	-
Long-run pre-coated steel with ordinary building paper	231	36	2507	566
Long-run pre-coated steel with fire-retardant building paper	336	91	4182	785
Metal tiles without building paper	323	-	3861	-
Metal tiles with building paper	421	100	4312	1335
Metal tiles with fire-retardant building paper	361	47	3687	558
Concrete tiles without building paper	90	-	366	-
Concrete tiles with building paper	125	14	2108	214
Concrete tiles with fire-retardant building paper	185	48	1831	521

Table 1. Condensation amounts measured for various roof specimen types

The peak figure for cladding condensation is on average 34% higher if building paper is present and, except for metal tiles, 98% higher on average if fire-retardant building paper is present. (For metal tiles the figure is 12% higher). Integrated condensation figures are much more widely scattered but, except for metal tiles, the integrated condensation is higher when building paper is present than when it is not.

The balances used were sensitive enough to easily detect the transfer of moisture dripping from the cladding to the building paper. Also, since a small section of both the cladding and the building paper was removed once an hour, the tendency for the cladding to drip or not could be observed visually. Aside from very rare accidental transfer due to clumsy handling, no dripping was observed, despite the fact that the condensation density on the claddings became quite high in some cases.

Other finer detailed results

The process of wetting and drying of the cladding has four stages. These are (see Figure 4):

1. *Cladding dry* - No condensation present on the cladding. Characterised by the cladding temperature being greater than the cavity dewpoint temperature.

2. *Cladding wetting* - Condensation accumulating on the cladding. Characterised by the cladding temperature being below the cavity dewpoint temperature.

3. *Early cladding drying* - Condensation drying off the cladding. Actual condensation density high. Characterised by the cladding temperature being equal to the cavity dewpoint temperature.

4. *Late cladding drying* - Condensation drying off the cladding. Actual condensation density low. Characterised by the cladding temperature being greater than the cavity dewpoint temperature.

Figure 4 illustrates these four stages clearly for concrete tile cladding. The figure is interesting also in that at hour 26 a climate chamber control glitch increased the humidity in the lower chamber. The cavity dewpoint can be seen rising up to the cladding temperature, and condensation can be seen collecting, providing a nice illustration of the details of very short period condensation.

Although building paper collected significant quantities of moisture, most of this accumulation was hygroscopic. True condensation took place only during very brief periods. Figure 5 illustrates this for concrete tiles, where a brief period of condensation accumulation can be seen when the temperature of the building paper becomes equal to the dewpoint of the surrounding air. Significantly, this building paper condensation phase takes place while the cladding is drying, implying that, during this period, moisture is being transferred from the cladding to the building paper through vapour transport across the cavity.

Discussion

The presence of more condensation when building paper is present was unexpected.

Closer inspection of the temperatures and dewpoints revealed how this unexpected result comes about. When building paper is present, the temperature drop across the roof specimen affects both the building paper and the cladding. Without the building paper this temperature drop appears across the cladding only. Thus, when building paper is present the temperature drop across the cladding must be less than it was without the building paper. In turn this means that the underside of the cladding must be closer in temperature to the radiation temperature (upper chamber) - in particular the cladding must be colder when the radiation temperature is low. Figure 6 illustrates how this effect comes about, and Figure 7 shows particular data observed for concrete tile specimens.

If, however, the cladding temperature is lower, it falls below the external air (lower chamber) dewpoint sooner and rises above the external air dewpoint later, meaning that the onset of condensation occurs earlier and finishes later. Furthermore, during condensation the cladding is colder when building paper is present, so it is likely that the vapour pressure difference is higher, driving moisture to condense on the cladding.

A secondary mechanism is also operating. The building paper is hygroscopic and therefore has a large influence on the relative humidity of the small cavity between the building paper and the cladding. Under the conditions being simulated, the building paper becomes very wet and therefore tends to control the relative humidity next to the cladding to a value close to 100%. This has the effect of maximising the vapour pressure driving force between the cavity air and the cladding, increasing the rate of condensation. This probably also explains why there tend to be even larger amounts of condensation when fire-retardant building paper is used since, due to the presence of fire-retarding chemicals, it is more hygroscopic than ordinary building paper. Figure 8 shows this higher cavity humidity with building paper for metal tile cladding.

Conventional wisdom also says that excess condensation on the cladding will drip onto the building paper, to be held there until conditions allow it to evaporate and be ventilated away. No such dripping was observed visually or measured quantitatively. It is clear that conditions would have to be quite harsh for drip to occur. Plainly, this mechanism, although plausible, does not occur over the wide range of condensation levels seen here, viz. up to more than 400 g/m^2.

Implications and Conclusions

These experiments have shown quite clearly that the conventional wisdom is incorrect - the presence of building paper actually *increases* the amount of condensation appearing on the cladding, not vice-versa. Conventional wisdom is also incorrect in assuming that excess condensation drips onto the building paper. This was not observed. These are scientific results of some interest as they were totally unexpected; although the explanation is straight-forward, and obvious in retrospect.

Practically, this result is probably unimportant. Given the non-existence of drip, the experiments indicate that very large amounts of cladding condensation would be necessary to create problems, say by causing degradation of the timber members of the roof construction, or finding its way onto the insulation and severely undermining its effectiveness. Such levels of condensation were not measured in these experiments and it seems certain that they would only occur under unusual conditions, such as in the presence of excessive construction moisture, or if large quantities of moisture were being unwittingly vented into the roof space. If such conditions occurred, then it is probable that the building paper would function in the way it had been assumed it functioned - i.e. the grossly excessive condensation on the cladding would drip and be held on the building paper until conditions allowed it to evaporate and be ventilated away.

References

Cunningham, M.J., Bassett, M. R., McQuade, D. & Beckett, M., 1994. A field study of the moisture performance of roofs of occupied newly constructed timber framed houses. Building and Environment, 29, No 2,p 173.

Leslie, S.F. & Trethowen, H.A., 1977. A Computer File of New Zealand Climate. NZERD Report, No 21, April.

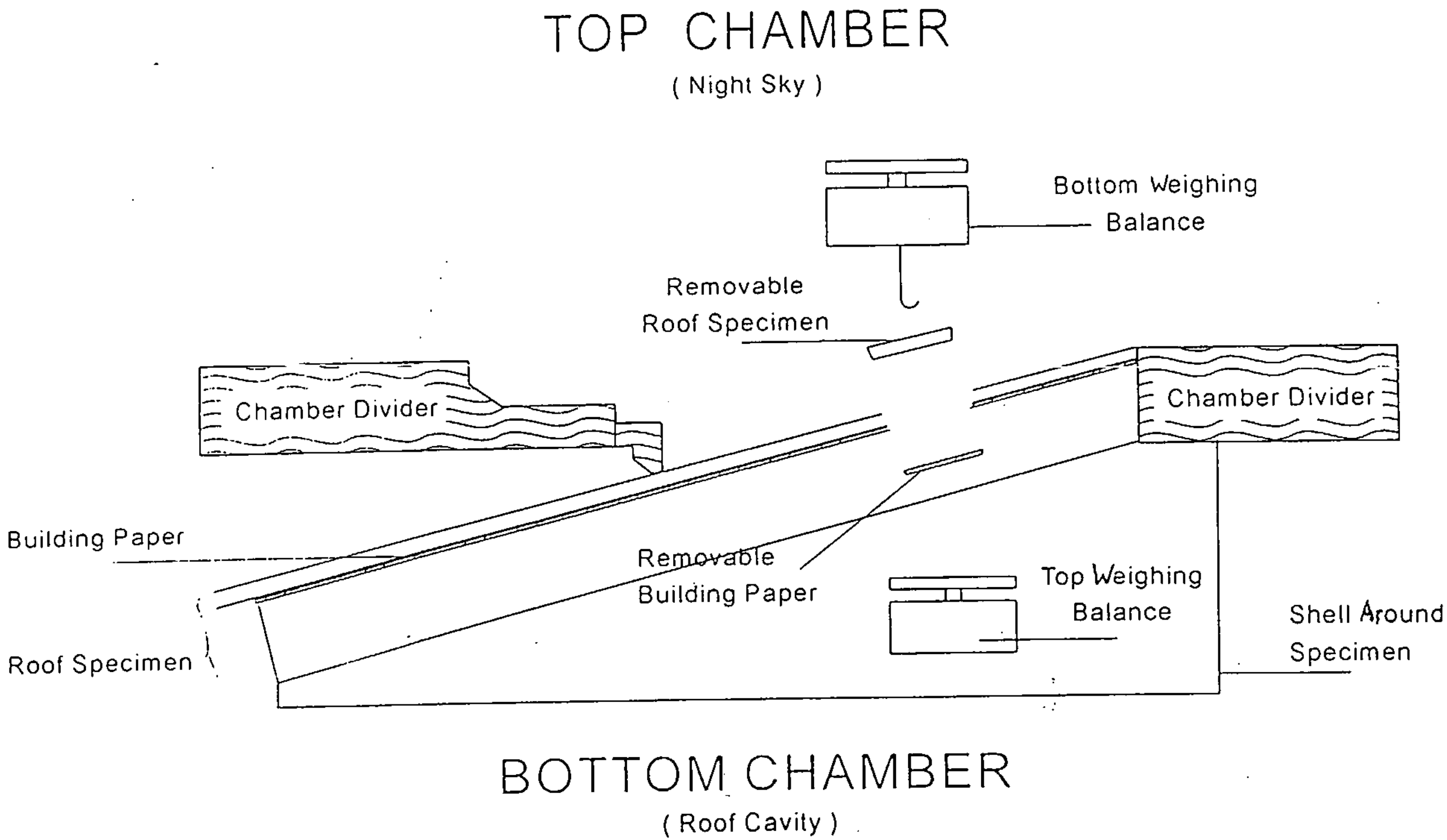


Figure 1. Diagram of the Test Specimen in the Controlled Climate Chambers

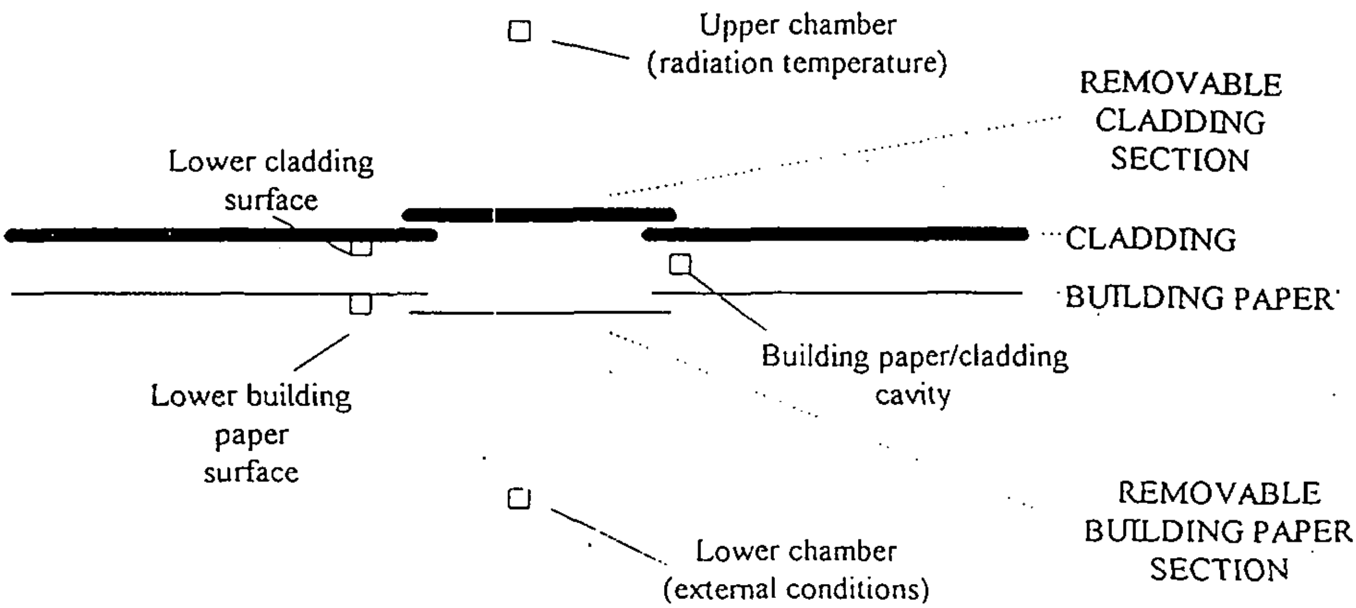


Figure 2: Location of sensor pairs (temperature and relative humidity) in roof samples

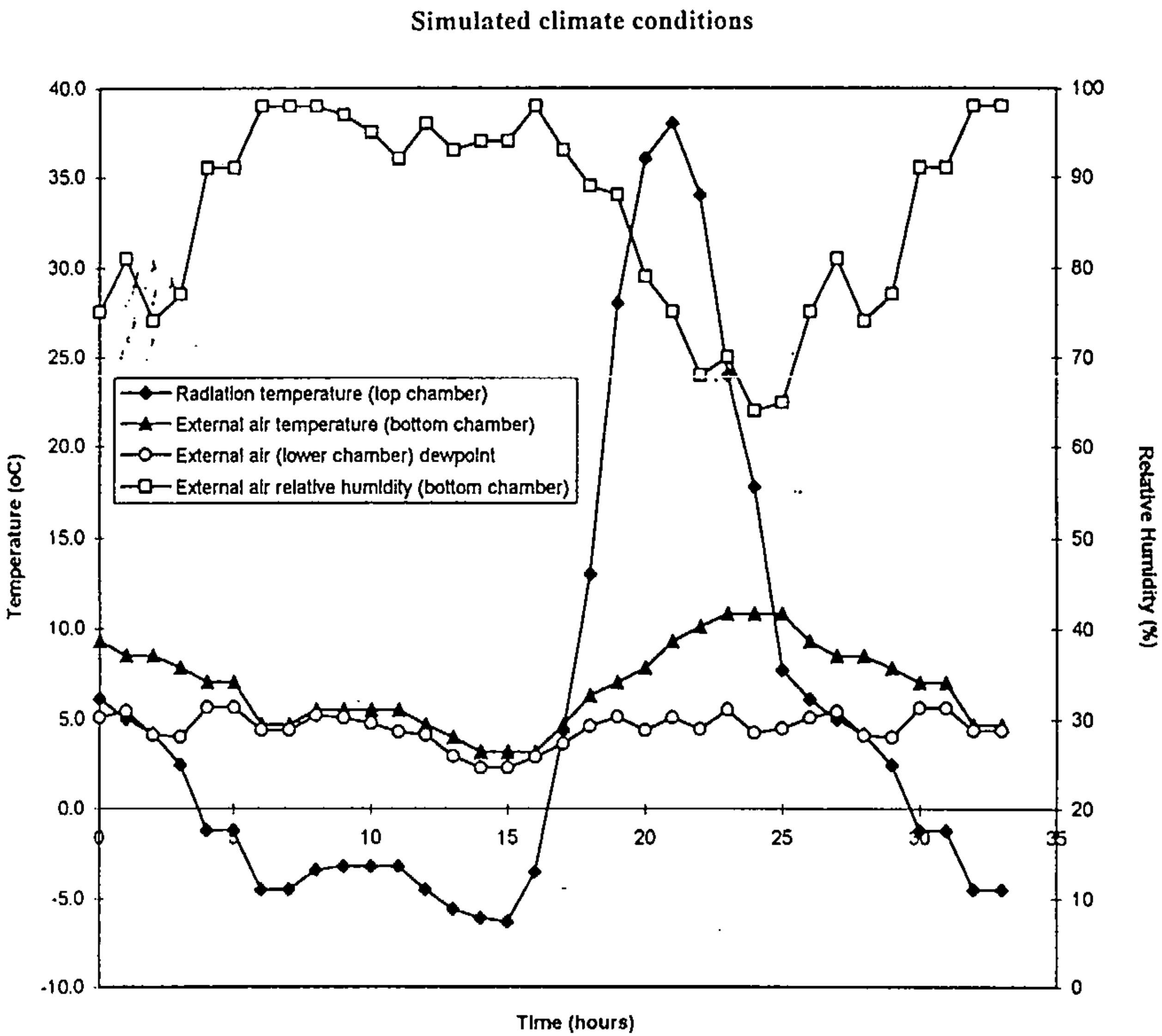


Figure 3: Simulated climate used in all the night sky condensation experiments

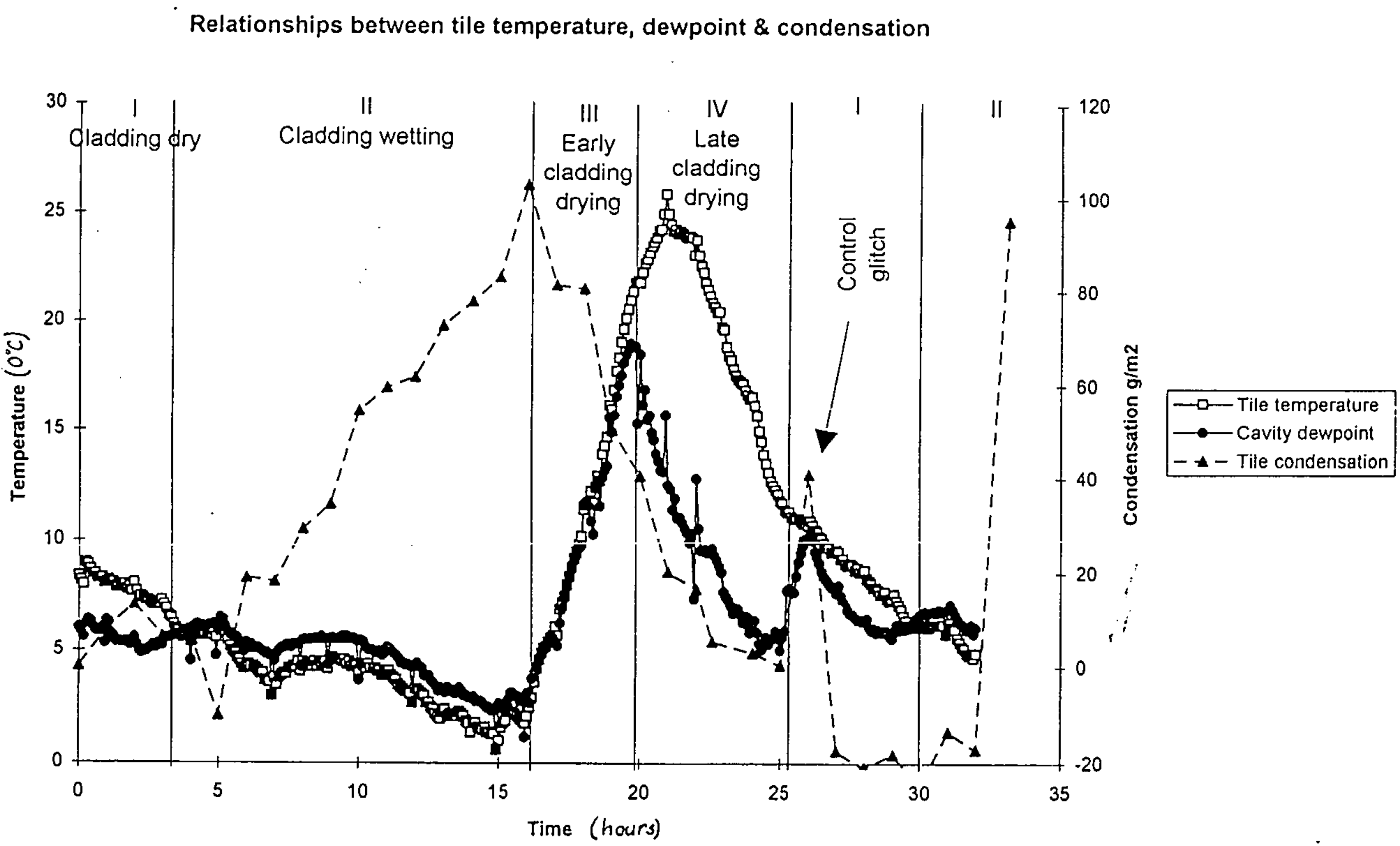


Figure 4: Four-stage condensation mechanism on roof claddings

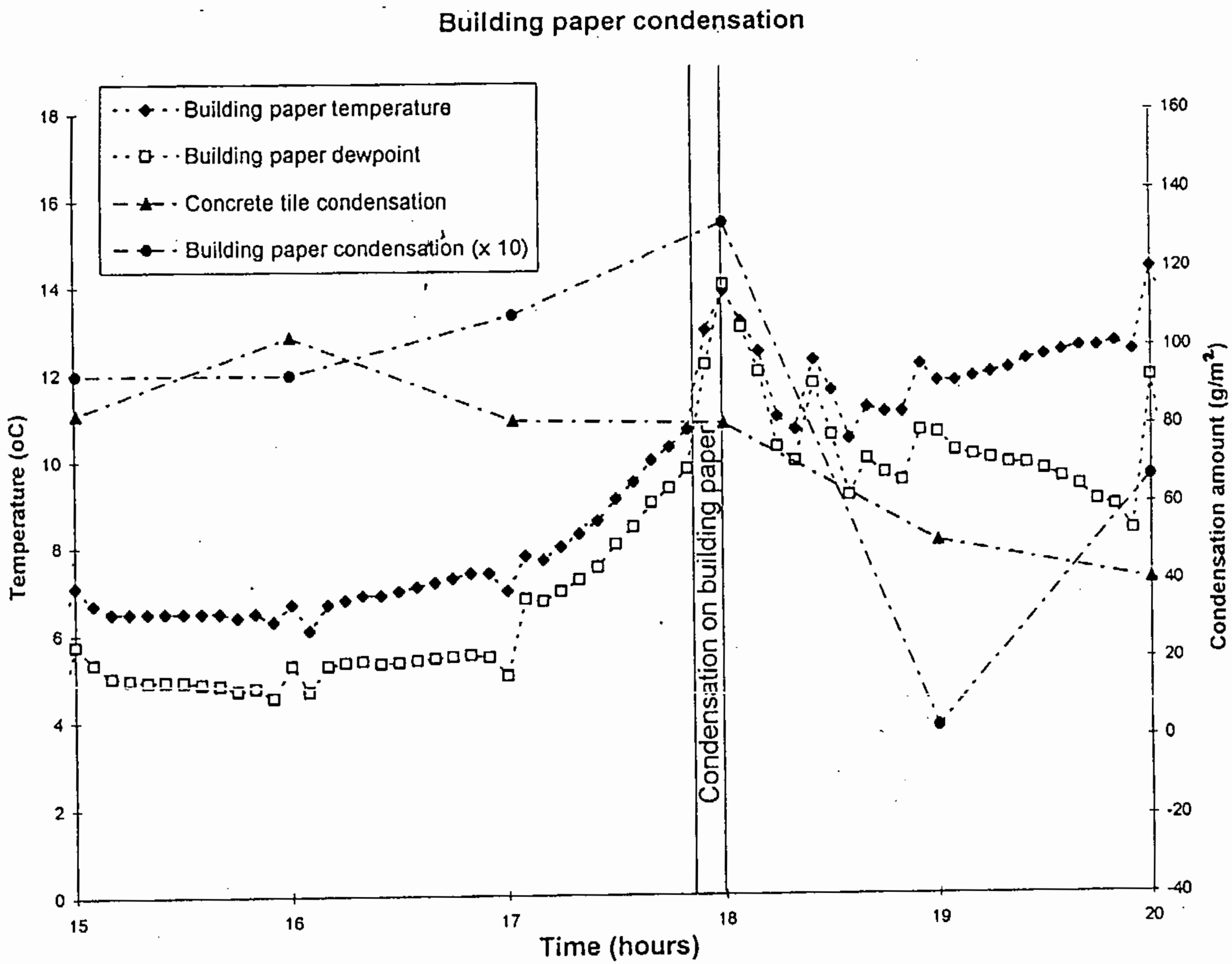
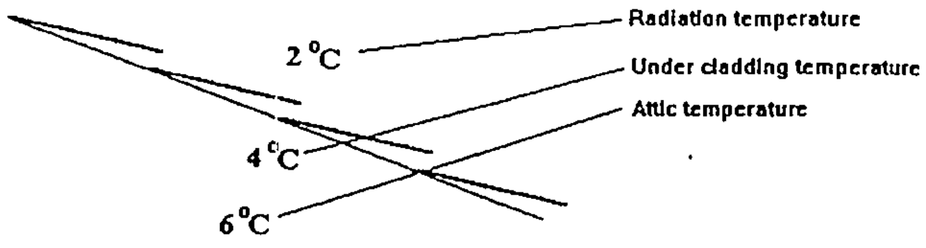
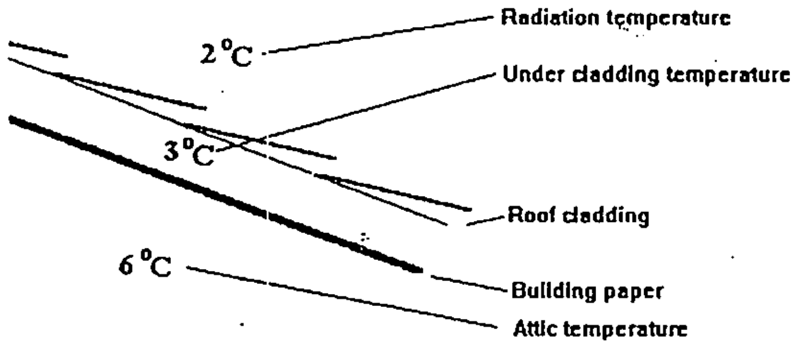


Figure 5: Building paper conditions showing a short period of condensation taking place while the concrete tiles are drying. Moisture transfer from the cladding to the building paper is taking place by vapour diffusion



(a) Cladding without building paper



(b) Cladding with building paper

Figure 6: Showing how the temperature under the cladding can be colder if building paper is present

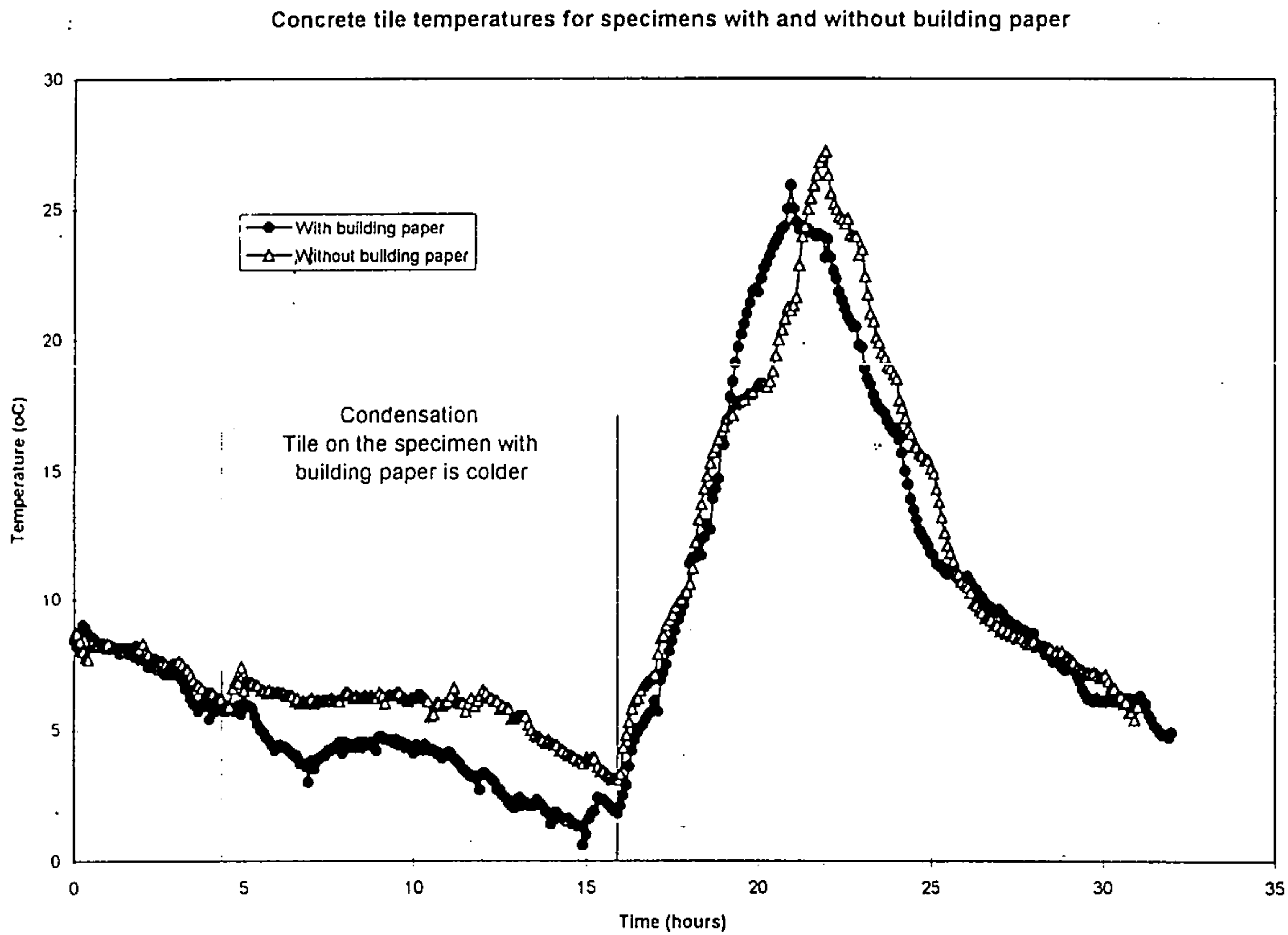


Figure 7: Concrete tile specimens showing that the tile with building paper is colder than that without building paper during periods of condensation

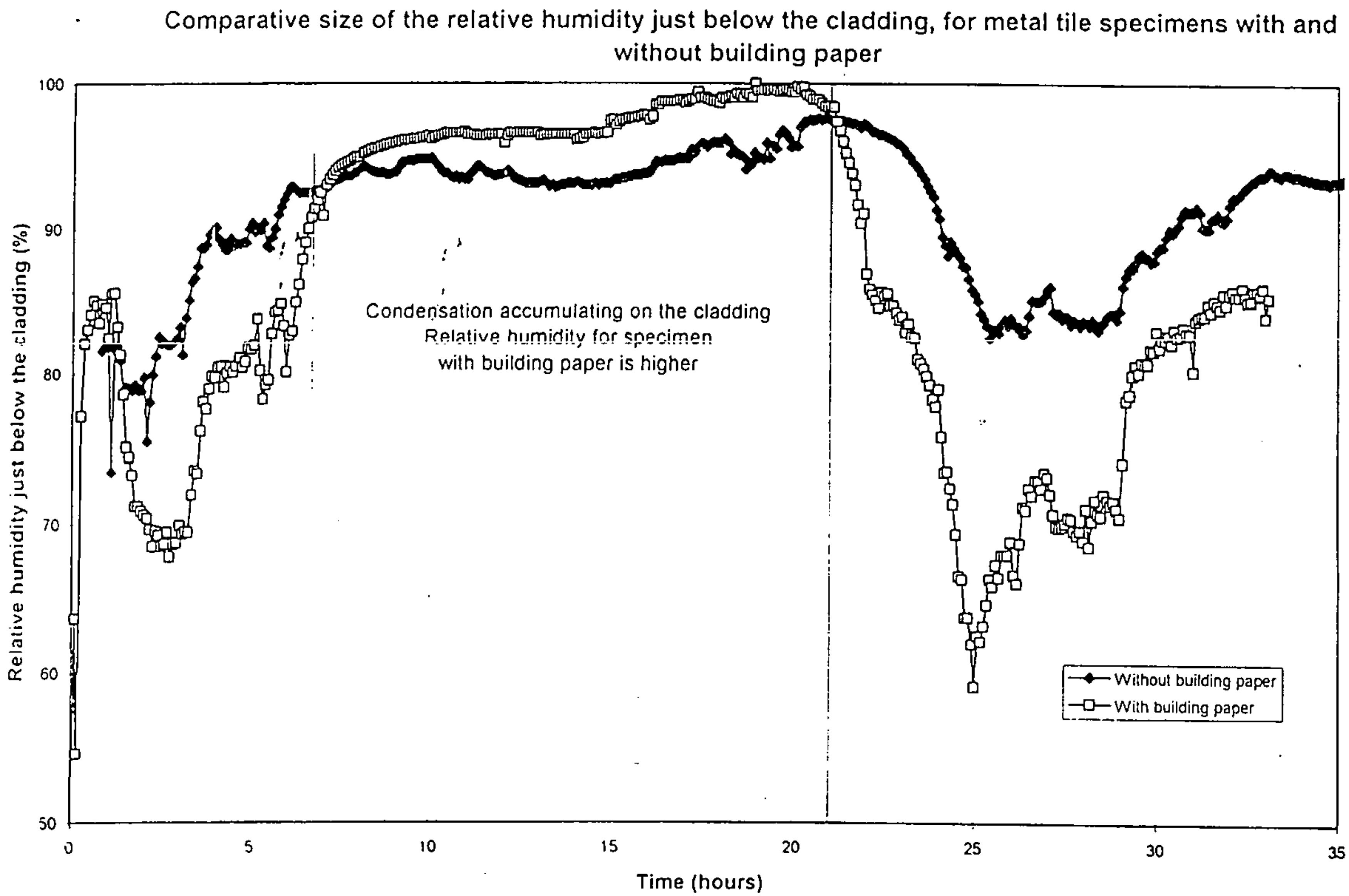


Figure 8: Relative humidities just below the cladding for metal tile specimens showing that, during condensation, the relative humidity for the specimen with building paper is higher

Solar Driven Moisture Transfer

Introduction

Solar-driven moisture transfer (SDMT) occurs when an absorbent cladding, such as concrete tiles, absorbs rain, some of which is later driven deeper into the roofing system by solar radiation. BRANZ has carried out extensive work on this mechanism (Cunningham et al, 1990), and has observed that underlay can help lessen the size of the effect.

Method

Physical structure of rig

BRANZ's SDMT rig consists of a frame arranged to support a $1m^2$ test roof specimen at an angle of 25°C (see Figure 9). A plastic bag is placed below the specimen, sitting on a heat plate exchanger simulating the ceiling. A rain tray, consisting of a shallow constant-head tank with an array of 1.5 mm holes drilled in its base, is placed above the specimen. This can be moved out of place to allow radiant heaters, simulating the sun, to be switched on.

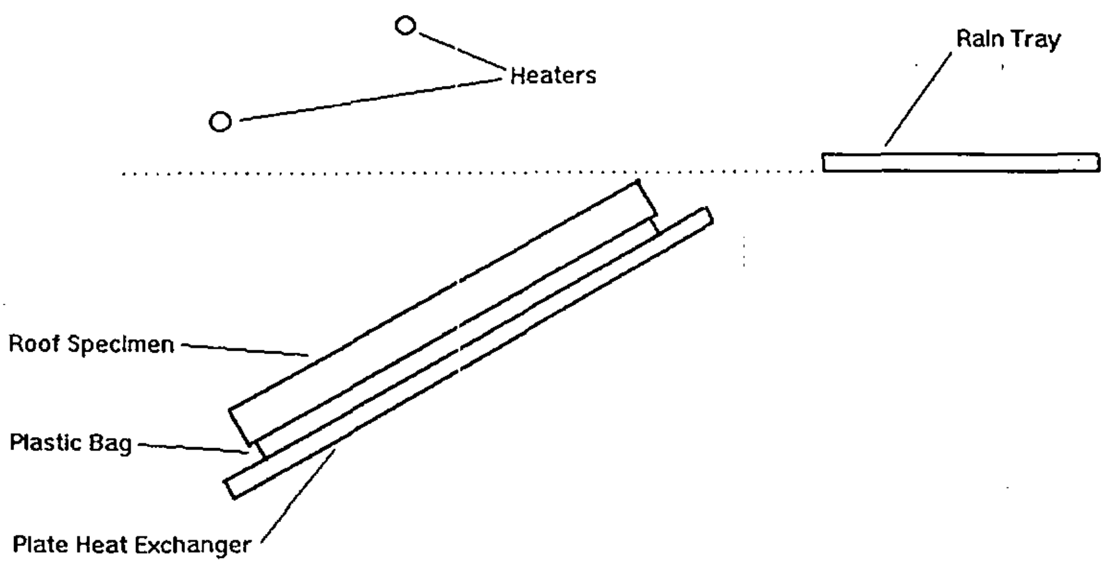


Figure 9. Diagram of the Solar Driven Moisture Transfer Rig

Measurement

Each specimen was subjected to the equivalent of 10-15 mm rain over a period of 16 hours, after which the plastic bag was checked and, if necessary, weighed to assess the amount of water penetrating the roofing system. The specimen was then subjected to four hours of radiation, equivalent to a normal solar flux of 750 W/m^2.

Long run pre-coated steel, metal tiles and concrete tile roofing systems with and without underlay were tested.

Results

The results of this testing are summarised in Table 2 below.

Specimen type	Rain penetration (grams)	Solar driven moisture (grams)
Long run pre-coated steel without underlay	0	0
Long run pre-coated steel with underlay	0	0
Metal tiles without underlay	0	0
Metal tiles without underlay	0	0
Concrete tile without underlay	6	27
Concrete tile with underlay	9	1

Table 2: Solar-driven moisture transfer into various roofing systems

Although it is clear that an underlay improves the performance of concrete tile specimens, the quantities of moisture involved are insignificant.

Conclusions

Solar-driven moisture transfer is not an issue with the roofing systems tested in this study. Small amounts of moisture were driven though concrete tile roof specimens, and these quantities were reduced with the use of underlay, but the quantities involved were not significant.

References

Cunningham M.J., Tsongas, G.A. & McQuade, D. 1990. Solar-driven moisture transfer through absorbent roofing materials. ASHRAE Trans, part 1, p465.

Loss in R-value Due to Wind Penetration into Insulations

Introduction

It is known (Anderson, 1981, Guy and Nixon, 1990, Silberstein, 1993) that if air flows with sufficient velocity over insulation, and if the insulation, is sufficiently air permeable, it will lose some of its thermal resistance (R-value). Since it is probable that different roofing systems will allow differing amounts of air into their attic space, the question arises whether these different roofing systems have significantly different R-value losses under windy conditions.

If there is no underlay, it may be expected that there will be some increase in air movement in the roof space, and possibly some reduction in insulation value of any porous insulants. Also, if there is no underlay, the small contribution made to insulation by the space formed between cladding and underlay would not be present.

Roof underlays are normally installed under metal roofing claddings but not under ceramic or concrete tiles of normal pitch (>17°). NZS 4206: *Concrete interlocking roofing tiles*, (SNZ 1992) requires underlays under tile roofs of less than 17° pitch.

Method

A sparse literature exists describing the overall roof insulation level achieved in-situ, as affected by the presence or absence of roof underlay. This literature is examined and an assessment made of the significance of R-value loss due to wind penetration.

Tiled roofs without underlay

Anderson's studies in 1980-81 (Anderson, 1981) were on tiled roofs in Britain which were relatively freely vented, probably not dissimilar to New Zealand tiled roofs without underlay. He showed that air movement in a roof space reduced the insulation value of fibrous insulation, but not that of closed-cell insulants.

Anderson's data showed that the measured in-situ thermal resistance of fibrous insulation varied with the local air speed near the insulant, as given in Table 3.

Local air speed (m/s)	0	0.25	1.0
Observed R-value (m^2°C/W)	1.8	1.5	0.98

Table 3: Thermal resistance of fibrous insulation as a function of local air speed over the insulation

Anderson also showed a connection between external and roof space air speed, as shown in Table 4.

External wind speed (m/s)	0	10	30	60
Roof space air speed (m/s)	0	0.03	0.09	0.18

Table 4: Anderson's (1981) correlations between external and roof space air speed

By combining Table 4 with data interpolated from Table 3, a likely relationship can be deduced between achieved ceiling insulant R-value and external wind speed, shown in Table 5.

External wind speed (m/s)	0	10	30	60
Roof space air speed (m/s)	0	0.03	0.09	0.18
Insulant R-value (m^2 °C/W)	1.8	1.75	1.70	1.55
Probable total roof R-value (m^2 °C/W)	2.20	2.15	2.10	1.95
% loss in R-value	0%	2%	5%	11%

Table 5: Penetration of external wind into roof space and consequent loss of R-value

For a tiled roof of overall R-value of 2.2 m^2 °C/W, containing fibrous insulation, the combined change in thermal insulation due to an underlay will vary from about 10-12% in normal winds, to about 20% in extreme storm conditions.

In turn, the R-value for the entire roof system will be reduced by perhaps 5% for normal winds.

Roofs with underlay

Silberstein (1993) reported data from a number of sources where underlay is present. The roof cladding type was not specified. He reported that roof air speeds did not correlate with outdoor wind speeds at all for winds up to 7 m/s. The maximum roof-space air speed was 0.16 m/s, and 90% of all measurements were below 0.1m/s. This in turn would mean that R-value loss must be very low (see Table 5).

Other measurements

More recent measurements by Guy and Nixon (1990) showed virtually no loss of insulation at local roof-space air speeds up to 1 m/s or more, for "...various commercially available loft insulation materials.....including glass wool rolls (60, 100, and 140mm thick), other mineral wools, and several blown wool products...". Losses occurred at higher air speeds, to 10-20% at 2 m/s.

It should be noted that, for low density fibrous insulation, a very significant decrease in R-value occurs if the temperature drop across the insulation is too great (e.g. more than about 22°C in blown loose-fill fibreglass), see for example Delmas and Wilkes (1992). This loss in performance arises from internal convection in the insulation and is not a wind effect. The loss in performance can be overcome by covering the top of the insulation, for example with building paper.

The gap between the cladding and the underlay

The effect on R-value of omitting of this gap has been known for a long time, and is reported for example in BRANZ booklet C.1 (1978) as contributing approximately 0.2 m^2°C/W to the total roof system thermal resistance. There is no indication of any need to review this estimate.

Conclusions

For a tiled roof without an underlay, with fibrous insulation, of overall R-value of 2.2 m^2 °C/W, the loss in R-value of the insulation over a similar roof with underlay will vary from about 10-12% in normal winds, to about 20% in extreme storm conditions.

In turn, the R-value for the entire roof system will be reduced by perhaps 5% for normal winds.

Hence, no significant loss in R-value with fibrous insulation is expected if underlay is not present.

References

Anderson, B.R., 1981. Measurements of the heat loss through an insulated roof. Building Services Engineering Research and Technology. 2, No. 2, p 65-72.

Anderson, B.R., 1990. The assessment of U-values for insulated roofs. Building Services Engineering Research and Technology. 1, No. 3, p 119-122.

BRANZ Booklet C.1 1978. A Construction Guide to Home Insulation. April. Building Research Association of New Zealand, Wellington.

Delmas, A.A. & Wilkes, K.E., 1992. Numerical analysis of heat transfer by conduction and natural convection in loose-fill fiberglass insulation - effects of convection on thermal performance. Oak Ridge National Laboratory, report ORNL/CON-338.

Guy, A.G. & Nixon, J.A., 1990. Effects of air movement on performance of loft insulants. Building Technical File, No. 28, p 39 - 45, Jan.

Silberstein, A., 1993. Hygrothermal performances of mineral wools in roofs and walls. CIB W40 Meeting Budapest, Sept., CIB, Budapest.

Standards New Zealand. 1992. Concrete interlocking roofing tiles. NZS 4206. Wellington New Zealand.

Weathertightness Due to Pressure Equalisation

Introduction

It is well known that a second layer behind a roof or wall cladding can play an important role in preventing weather penetration by reducing the air pressure across the cladding necessary to drive rain into the structure. This mechanism is known as pressure equalisation (Baskaran and Brown, 1992).

In detail, the air pressure existing across a cladding-underlay system must fall into two components: part of the pressure difference appears across the cladding and part across the underlay. If the outer cladding is air-loose and the underlay is air-tight then most of the air pressure difference appears across the underlay and very little across the cladding (see Figure 10). This means that very little air pressure difference exists to drive rain through gaps in the cladding and into the roofing system.

Since roofing systems without underlay do not have the two layers necessary for pressure equalisation, this mechanism of weather penetration prevention is not available.

In this report the possible size and effectiveness of air pressure equalisation for various roofing systems is estimated by calculation.

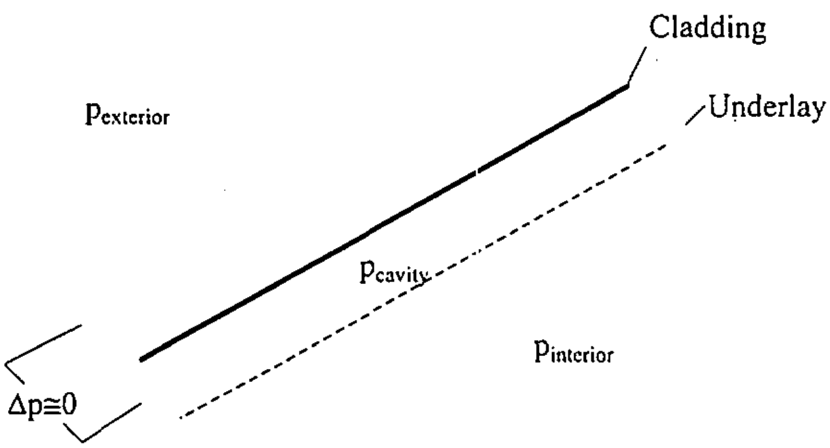


Figure 10: Air pressures across a roofing system with an underlay, under conditions of pressure equalisation - cavity pressure approximately equal to external pressure.

Method

Air pressure differences across roofs

The behaviour of air as it passes as wind over roof constructions is difficult to analyse without complex computer mathematical modelling known as computational fluid dynamics (CFD). This is very time consuming and expensive and not appropriate here. Instead, an approximate analysis has been carried out, not involving extensive computer modelling but based on a simplified understanding of the wind environment of low-rise residential/industrial buildings, as explained below.

If the air pressure exerted on a roof is averaged over a period of time in excess of 10 seconds, it is found that roofs of pitch lower than 30 degrees are often under suction, rather than pressure. This depends on the ratio of building height to length in the direction of the air flow, and changes with the wind environment about the building. However, roofs will be subject to wind gusts of two-second time period (and considerably less) which subject them to positive and negative (pressure and suction) wind loads of some magnitude, depending on roof pitch and building geometry. Pressures are influenced by the area of dominant roof openings, as mentioned in C4.6 of NZS4203:1984 *Code of Practice for General Structural Design and Design Loadings for Buildings* (SNZ, 1984), and the height-to-depth ratio of the building. It is impossible to determine the air pressure that a specific section of roofing system will be under at any one time, without recourse to statistical methods.

Boundary layer theory suggests that, for the example of when a roof and supporting structure is subject to wind, streamlines will carry over a roof and will separate at surface changes, meaning that the roof-ridge may always be in average suction. The leading eaves and some of the lower roof may be constantly under average positive pressure (Latta, 1991), but not usually the roof as a whole. Under these conditions only two types of leaks occur, viz. gravity leaks, acting on surface water, and leaks due to water bridging a small gap and being blown inwards by an instantaneous air pressure difference.

Even though the entirety of a roof is not usually subjected to a bulk pressure environment at any one time (as localised air leakage can contribute to the larger overall air leakage), assuming such a bulk pressure makes a useful starting approximation for examining the weathertightness of the system. Therefore, in this study, the weathertightness modelling of a roofing section will be for the worst case scenario, that of a positive pressure on the cladding exterior.

Theory

The degree of pressure equalisation that occurs in any cladding system can be measured by the quantity *pressure equalisation percentage* (PEP). This is obtained from an equation (1) which averages, over time, the pressure difference between the external air pressure due to wind, and the air pressure within the building cladding (Burgess, 1994). In the following analysis, a high pressure equalisation percentage (PEP approaching 100%) indicates that there is no air pressure difference across the cladding, resulting in good weathertightness behaviour. On the other hand a PEP of 50% indicates no pressure equalisation, therefore no contribution is able to be made to the weathertightness performance. A roofing system with a 100% PEP results if a cladding system is constructed with an air-loose outer cladding and an inner air-tight underlay, because most of the pressure difference across the system will occur across the underlay and there will be no pressure difference across the outer cladding layer, and therefore no force to drive water entry.

The weathertightness of three differing roofing cladding systems, constructed in varying materials with varying methods, was investigated by estimating the PEP of each system by calculational models.

The generic roofing types examined were:

- Heavy unitised roofing units with and without underlay, such as concrete tiles;
- Lightweight agglomerated-section units with and without underlay, such as pressed metal tiles;
- Integral cladding systems with and without underlay, such as long-run galvanised or pre-coated steel roofing.

A numerical model designed to determine the pressure equalisation performance of jointing systems 'PERAM' (Burgess, 1994), was used to aid in the estimation of air pressure differences across roof claddings under wind. This numerical model is based upon the use of Equation 1 in Burgess, 1993 viz:

$$PEP(f) = 100\left(1 - \frac{1}{2PT}\int_{0}^{T}\left|P_e - P_c\right|dt\right)$$

where

f is the pressure frequency
T is the pressure period
P is the pressure amplitude
P_c is the instantaneous interior air pressure
P_e is the instantaneous exterior air pressure

The equation effectively calculates the mean deviation from a perfect pressure response of P_c (interior air pressure) to P_e (exterior air pressure), as detailed in the preceding section, assigning a number indicative of the level of pressure equalisation that is able to occur within a certain system taken from measurements of the joint cavity pressure response, and the driving pressure (assumed sinusoidal). The model PERAM allows cladding joint air pressure variations to be calculated from a knowledge of the geometry of the system (Burgess, 1993, 1994).

In this study, the geometry of the roofing cladding systems has been determined from analysis of construction details of the various roofing systems, and these figures served as the numeric geometrical input to PERAM. PERAM was then able to output PEP percentages for the geometrical configurations of roofing systems as input. Actual roof construction details differ somewhat for 'identical' systems, due to variable gap dimensions between overlapping units and at other junctions, as well as the placement and edge profiles of fascia boards to provide a seal between roof cladding and structure. To allow for this variability, the geometry of between 2 and 4 'typical' constructional varieties were input to PERAM, and the output percentages averaged for each case. These values are given in Table 6.

Following the determination of differential air pressures across each roofing element in the form of a PEP, the transport of liquid water driven by these air pressure differentials was assessed, so the degree of wind-borne rain ingress through roofing systems could be inferred.

Results

The calculations confirmed that underlay beneath roofing cladding may act as a relatively impermeable layer, which can serve to support most of the air pressure that is created across the roofing system by the action of wind. PEPs calculated are contained in Table 6.

Roof slope	Roof type	Typical PEP with building paper	Typical PEP without building paper	PEP benefit from building paper?
30 degrees	Integral	50	50	No
	Lightweight - agglomerate	55	50	Little
	Heavy - unitised	98	80	Yes
45 degrees	Integral	50	50	No
	Lightweight - agglomerate	52	50	Little
	Heavy - unitised	90	80	Some
60 degrees	Integral	-	-	No data
	Lightweight - agglomerate	50	50	No
	Heavy - unitised	82	75	Some

Table 6. Summarised effect of roof slope, type of cladding and presence or absence of underlay on the pressure equalisation percentage of roofing cladding systems

Behind each entry in Table 6 there are several calculations at different building height/breadth ratios and cladding construction air-tightnesses. The detail of the mechanism of pressure equalisation occurring within these roofing systems could not be specifically determined due to the extremely complicated modelling required of airflow patterns, through and around air-permeable outer claddings with variable supporting structures. Experimental testing is required to make more information available, and to determine whether constructional differences within a generic system may be responsible for differing degrees of weathertightness.

However, the calculations have shown that an improvement of the pressure equalisation performance of roofing systems (and therefore weathertightness) through the use of underlays is possible for unitised roof cladding systems, but not for integral cladding systems, due to their lack of air-permeability.

Conclusions

Roofing underlays do not significantly affect the air pressure equalisation performance of integral roofing, e.g. long-run galvanised or pre-coated steel. It is possible, however, that weathertightness advantages may be gained at roof edges with suitable construction techniques.

Roofing underlays do beneficially affect the pressure equalisation performance of heavy unitised roofing systems, e.g. concrete tiles, and so theoretically improve the weathertightness performance of these systems.

Roofing underlays do affect the pressure equalisation performance of lightweight agglomerate-section roofing systems, e.g. metal tiles, but to a lesser degree than the heavy unitised systems, meaning that little pressure equalisation weathertightness advantage is gained by using underlay with this roofing type.

Mathematical models have allowed a preliminary assessment to be made of the potential improvement (or otherwise) in weathertightness when underlay is used with roofing systems. However, experimental testing is required to determine the degree and detail of this weathertightness enhancement before definitive conclusions can be drawn on the significance of this improvement.

References

Baskaran, B.A. & Brown, W.C., 1992. Performance of pressure equalized rainscreen walls under cyclic loading. J Thermal Insl & Bldg Envs, 16, p183.

Burgess, J.C., 1993. Air pressure equalisation in rainscreened joints by geometric alteration. Accepted for publication in Building and Environment.

Burgess, J.C., 1994. Pressure equalised rainscreen joint modelling with the numerical model PERAM. Submitted for publication to Building and Environment.

Latta. J.K., 1991. Walls, windows and roofs for the Canadian climate. Internal Report No. 629, NRCC, Ottawa, Canada.

Standards New Zealand, 1984. Code of practice for General Structural Design and Design Loadings for Buildings. NZS4203:1984. Wellington New Zealand.

Overall Conclusions

This study investigated the performance of roofing systems with and without underlay. Four mechanisms were investigated, viz. condensation under conditions of night-sky radiation (frosty clear nights); solar driven moisture transfer; the degradation of R-value due to wind penetration of insulation; and weather penetration. The first two mechanisms were investigated experimentally, and the last two by calculation and literature review.

Condensation - The presence of building paper was found to increase the amount of condensation appearing on the cladding under conditions of night-sky radiation, contrary to conventional wisdom. This is an interesting and unexpected result although the explanation is straight-forward. Practically, this result is probably unimportant because the levels of condensation observed, even under the quite extreme conditions simulated, were not sufficient to cause condensation drip off the cladding and onto the underlay.

Solar-Driven Moisture Transfer - In this mechanism, absorbent claddings absorb rain which is then driven deeper into the structure when the sun comes out. It was plausible that systems without underlay would not perform adequately with respect to this mechanism. In fact, experiments showed that all systems performed well.

Wind Penetration into Insulation - Some loss in roof R-value is possible if wind penetrates into the roof cavity and hence into the insulation. Literature searching and calculation suggests that this effect was not highly significant; for a tiled roof without an underlay with an overall R-value of 2.2 m^2 °C/W, the loss in R-value of the insulation over a similar roof with underlay is about 10% in normal winds. In turn, the R-value for the entire roof system will be reduced by perhaps 5%.

Weather penetration - Underlays allow the mechanism of pressure equalisation to come into play, whereby wind-created air pressure differences appear mainly across the underlay, leaving very little air pressure difference across the cladding itself to drive rain into the roof structure, thus enhancing the weathertightness of the roofing system. Calculations indicated that underlays improve the performance of heavy unitised systems (e.g. concrete tiles), improve a little the performance of lightweight agglomerated-section roofing systems (e.g. metal tiles), and do not improve the performance of integral roofing systems (e.g. long-run galvanised or pre-coated steel).

How much improvement occurs for what roof geometries and weather conditions cannot be determined by the approximate methods used. More definitive results await experimental studies now nearing completion.

Appendix A

Proprietary Products Used

Proprietary products used for the experimental work reported here were as follows:

Concrete tiles: Monier *Centurion* brand concrete tiles, nominally 420 mm × 330 mm weighing approximately 4.5 kg.

Long run pre-coated metal: Dimond Industries Ltd pre-coated steel, .55 mm thick, 5.884kg/m^2, 76mm between corrugations.

Pressed metal tiles: Derabond metal tiles, 1320 mm overall (uncut) length, weight 3.2 kg.

Building paper: INZCO Bitumac 360 self-supporting roof underlay. Three layers of kraft laminated with bitumen and reinforced with glass fibres.

Fire-retardant building paper: INZCO Flamestop 660 self supporting roof underlay. Heavy duty breather-type building paper complying with NZS 2295.

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