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# STUDY REPORT

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## AN ANATOMY OF MILDEW RISK WITH REFLECTIVE INSULATION

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# An Anatomy of Mildew Risk with Reflective Insulation

# An Anatomy of Mildew Risk with Reflective Insulation in Walls

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## 1. Summary

This paper attempts to allocate the contribution of different structural and operating features to the risk of mildew growth on the inside surface of lightweight external walls in New Zealand housing.

It presents a quantitative method based on predicted RH on the wall surfaces, suitable for a wide range of lightweight walls. These make allowance for local positional effects within a room.

The method makes use of the "Temperature Index" which is amenable to routine assessment during insulation testing. This method may be suitable for Handbook application.

The method is illustrated by its application to three light timber framed walls of different insulation grade, and predicts low mildew risk for insulated walls and about equal risk for reflective-insulated and uninsulated walls.

## 2. History

### 2.0 Outline:

Wintertime mildew growth on both walls and ceilings was commonplace in New Zealand housing until the late 1970's (1,2). At that time mandatory thermal insulation requirements came into effect (NZS 4218) (3) throughout the country. Although this has not been measured, there was perceived to be a progressive fall-off in the number of mildew complaints brought to the BRANZ advisory service during the 1980's. By the end of that period BRANZ advisory officers were prepared to support the idea that "mildew usually occurs only in uninsulated houses".

However, by that time, separate events were occurring that also associated mildew growth with reflective wall insulation, and a link was openly made by some building firms. It was not known whether the mildew problems were significant, and if so whether they were caused by, or merely associated with, the reflective insulation. Two groups of relevant factors quickly became evident:-

### 2.1 Social Factors:

a. **Price.** The use of reflective wall insulation offered the lowest first-cost method of complying with the insulation rules. This method of insulation became dominant in the lowest price housing. .

b. **Size and Layout.** The houses with reflective insulation tended to be smaller, and more compact (i.e. simpler shape). Both small size and simple shape tend to lead to "tighter" houses with a lower average rate of natural ventilation to dilute and expel the moisture produced by occupants.

c. **Occupancy.** Although these houses were smaller, they did not tend to have lower occupancy. Thus the amount of space per occupant, and the amount of ventilation per occupant, was less.

d. **Heating.** Presumably because these houses were occupied by people with less money, they tended to be less well heated.

   In many cases heating was by portable unflued gas heaters. These heaters release up to 2 kg water for each 1 kg fuel they consume (viz, 0.12 litre/kWh).

e. **Security.** Many of these houses are in neighbourhoods where occupants feel a need to keep their houses locked up for security reasons much of the time. This reduces the amount of user-controlled ventilation provided.

f. **Employment.** There appears to be a higher chance that all occupants will be out at work, or alternately that there may be "double-bunking". These factors also tend to result in lower ventilation and lower heating.

g. **Laundering.** With the highly compact design of these houses the laundry facilities tend to be brought closer into the living space. This can be a source of extra moisture.

### 2.2 Building Factors:

Any factors which lower the surface temperature at wall or other surfaces will raise the local surface humidity, and hence increase the mildew growth risk:-

h. **Insulation Value.** The gross insulation value of reflective insulation is rather lower than that of other types of insulation commonly in use.

i. **Location.** Different locations within a space have different surface heat-transfer coefficients, and consequently different surface temperatures.

j. **Thermal Bridging.** Any thermal bridging effect in a structure will have the effect of lowering the local surface temperature near the bridge.

k. **Vertical Temperature Gradients.** Because the cavity heat transfer is predominantly convective, vertical temperature differences will be generated, leading to extra cooling near the bottom edge of each wall cavity.

l. **Bottom Plate Chilling.** Many of the affected houses have overhanging, or cantilevered, floor edges. This allows additional cooling of the bottom edge of the wall. This factor is not exclusive to foil-insulated walls but is often associated with them.

m. **Thermal Inertia.** In the period around local sunrise it is likely that room temperature begins rising rather more quickly than the bottom plate temperature. In a house with potential mildew problems, there will be moist materials which will begin drying at this time, thus raising the moisture content of the air. This will increase the risk that any cool surfaces (e.g. against frame members and particularly the bottom plate) will collect condensate.

n. **Vapour Permeance.** The moisture transmission capability of the building envelope is reduced by reflective insulants.

The same process could occur with any insulant. It should be expected to be worse with reflective insulation because the starting temperature of the bottom plate is lower than with other insulants.

## 2.3 "Mildew Risk Score Sheet":

During early 1992 a trial "Mildew Risk Score Sheet" evaluation kit was designed at BRANZ and trialled amongst BRANZ staff. By various methods this Score Sheet includes allowance for the first eight factors in 2.1 and 2.2 above. This work has not been published and it is thought at present to be unsuitable for use by unskilled people. It asks for a series of (numeric) responses about house occupancy usage, house size and design, and ventilation practices. From these responses, estimates are derived of the moisture load and the mean ventilation rate, and are combined into a single predicted indoor vapour pressure excess over outdoors. This excess is finally compared to the building insulation and heating practices to forecast likely mildew levels.

The Mildew Risk Score sheet is built on several past and continuing projects at BRANZ, and uses some of the information from (4). Relevant BRANZ projects have also been conducted concerning thermal insulation, moisture behaviour, and building ventilation. It has been found (6) that many of these small compact houses are extremely airtight and receive only 0.2-0.3 air changes/hour natural ventilation. At these low air change rates even minor ventilation reductions will push up the vapour pressure excess very quickly. Indoor vapour pressure has exceeded outdoors by less than 2 mbar in non-problem houses but 3-4 mbar or more in problem houses which have been surveyed (see Section 4.2).

## 3. General Factors

### 3.0 Conditions for Mildew Growth:

Common moulds or mildews all require moisture levels to be above certain levels in order to grow. This level varies with mould species, and is often taken rather loosely, as for example >70% RH (1). This loose description is usually given without comment as to whether it refers to the general room relative humidity, or to the humidity at the surfaces on which mould may grow. It will be seen later that they may be quite different.

Mildews are primitive plant forms,which grow on available surfaces. Like all plants, they need a supply of moisture, not only for growth but perhaps even more importantly *for germination. Common mildews need to exceed some threshhold humidity for some* time (1-10 days) before they will germinate (10). Both the germination period and the subsequent growth rate vary according to temperature.

Laboratory tests on mildew growth rates are normally carried out in steady, well-controlled conditions, and the surfaces are in equilibrium with the room condition. Since the mildews grow on the surfaces, it seems likely that their growth would depend more on the moisture content of the surface on which they grow, than on the relative humidity of the air. Many building materials are hygroscopic, i.e. they will absorb or release moisture until they reach some equilibrium with the air humidity condition. These equilibrium states are well known for many materials (wood, plaster-board, cotton, wool, etc) and are called Equilibrium Moisture Content (EMC) or Sorption Curves. The RH at the surface of a material will be strongly influenced by its moisture content, as indicated by the sorption curve. Usually the moisture content will be a function of the mean local RH, but if there is some other moistening process then the moisture content will instead drive the local RH.

The local moisture content (m.c) of the surface therefore should be preferred as a mildew indicator over the RH of the air. In practice the moisture content of materials changes only slowly. If they reach some critical moisture content at all, then it is likely that this state will also be maintained for long enough to ensure germination of mildew spores.

For the purpose of this paper, the criteria for mildew growth will be taken as the mean RH at the local surfaces. A value of say 85% at the surface is perhaps consistent with the commonly used value of 70% in the general room humidity.

### 3.1 Basic Processes:

The physical processes accounting for mildew growth have been previously reported (1, 2) and are illustrated in Figure 1.

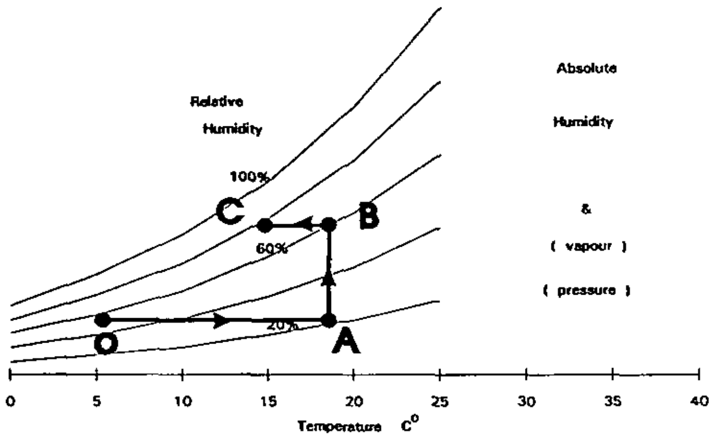



**Figure 1. Illustrating Indoor Moisture Conditions**

Figure 1 shows the progressive changes to ventilating air, and thus indoor air, as it passes through the house. Air at some outdoor condition 'O' is brought indoors where it becomes warmed to the indoor temperature at 'A'. It takes up some moisture to move to condition 'B'. 'B' is the general indoor condition. It is nearly always warmer than outdoors 'O', and has a higher moisture content. But it may be either higher or lower than the relative humidity at 'O'. In winter, the inside surfaces of external walls, windows, and ceilings are cooler than the indoor condition 'B', and so the final condition in those areas is indicated by 'C'. The surface RH at 'C' represents the risk of mildew growth on the surface at 'C'.

The calculation of the surface RH's is aided by several techniques. Psychrometric charts or tables can be used to predict the drop in RH as a result of heating from 'O' to 'A'. They can also be used to estimate the rise in indoor humidity from 'A' to 'B' if the increase in indoor vapour pressure can be estimated. Finally, there is a convenient parameter called the Temperature Index (TI) (see Eqn. 3), which is equal to (1 - CB/OA) and is a function of the insulation quality and of local surface resistance.

Clearly the objective is to keep point 'C' at as a low relative humidity as possible. This is achieved by keeping:

- OA large - i.e. enough heating to lower general indoor RH
  AB small - i.e. enough ventilation to dilute the moisture released indoors
- BC small - i.e. enough insulation to limit the effect of surface cooling

At any time the condition 'O' is substantially constant over the whole house. The (hypothetical) points 'A', however, will vary with location in the room, particularly from floor to ceiling. The (real) points 'B' will also vary with location, not only in response to the variations in 'A' , but also according to the degree of moisture absorption/emission which may take place at different heights. The points 'C' will be further dispersed in Figure 1 because there will be different degrees of local cooling at each point on the room surface, especially at corners and behind shielding furniture.

From first principles we have:-

$$OA = \frac{\sum \text{heat emission}}{\text{Overall building conductance}} \; \frac{(W)}{(W/^\circ C)} \qquad ^oC \qquad (1)$$

$$AB = C1 * C2 * \frac{\sum \text{moisture emission}}{R.V} \qquad \text{mbar} \qquad (2)$$

$$(4800/R.V) * \sum \text{moisture emission}$$

where C1 = 1600 mbar/( moisture content of air, g/g) (6)
C2 = 3600/(1000*ρ) ~ 3
ρ = density of air, ~ 1.2 kg/$m^3$
v = ventilation rate, $m^3$/s
V = room volume, $m^3$
R = air change rate, No./h = v*3600/V

**The 'Temperature Index'** (TI) (see Ref. 8):-

$$TI = \frac{T_s - T_o}{T_i - T_o} \qquad (3)$$

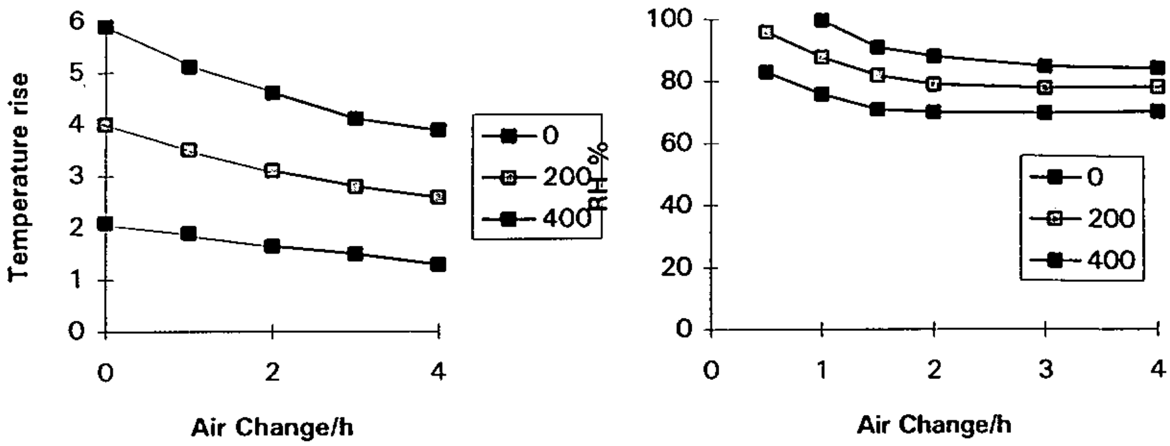
where: TI = Temperature Index at a point
$T_s$ = indoor surface temperature at that point
$T_i$ = mean indoor temperature
$T_o$ = mean outdoor temperature

(for some purposes, TI is taken at the coldest point on the surface. Here it is treated as a variable over the surface.)

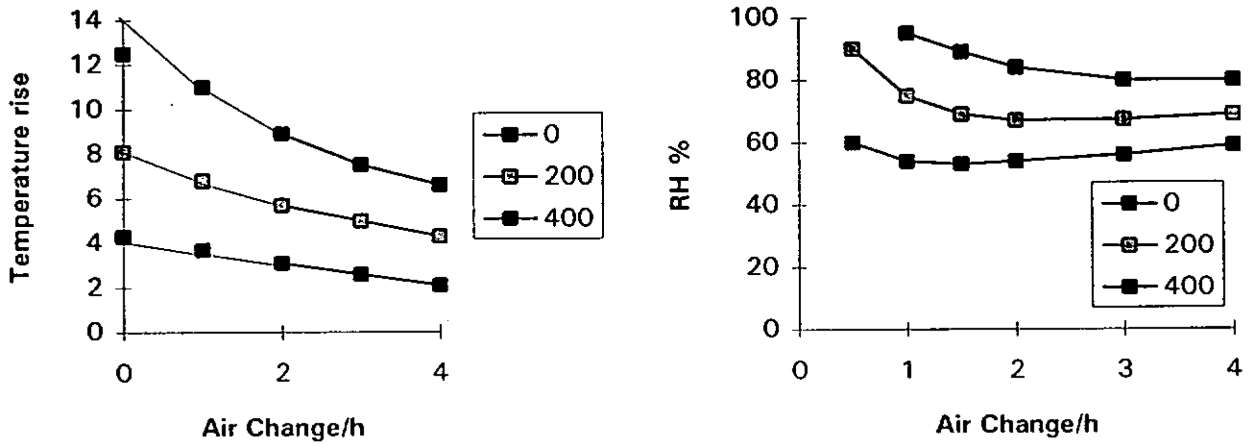
## 3.2 General Room Conditions:

The general room conditions in winter have been previously examined (2, 5). An illustration of the outcome from such studies for mid-winter conditions is given in Figure 2. and showed that:-

- -mildew growth would be difficult to avoid in any unheated, uninsulated bedroom at any ventilation rate .
- -at every heating and insulation level there is an optimum degree ventilation, too much ventilation becomes counterproductive
- -when both insulation and heating are provided, small ventilation rates (0.5 - 1.0 air change/h depending on moisture load) are sufficient to bring the indoor RH down to safe levels.




(a) Bedroom




(b) Kitchen

**Figure 2. Typical Warming and Relative Humidity Response of Rooms [redrawn from (2)].**

Notes - temperature rise is the increase over outdoor temperature
- different curves are for different heating levels, (Watts)
- outdoor humidity is 90%

Theoretical and field studies (e.g. 6) both indicate that the typical indoor conditions 'B' may have 2 - 4 mbar higher vapour pressure than outdoors. The observed values have been higher for "tight" houses with vapour barriers and lower for "normal" houses. Outdoor RH in New Zealand is typically high, 80% to 90%. A simple comparison as in Figure 1 on a complete psychrometric chart shows that indoor temperature must be kept about 7 °C warmer than outdoors if the condition 'B' is not to exceed 70% RH. From this simple observation BRANZ developed its first mildew risk diagnostic rule (Ref. 2).

**The "7° Rule"**
If there is winter time mildew, AND-

- - if average indoor temperature is less than 7 °C warmer than outside, there is not enough heating.
- - if average indoor temperature is at least 7 °C warmer than outside and mildew still occurs, there is not enough ventilation.
- -if 7 °C excess is difficult to maintain, there is not enough insulation.

### 3.3 The "Surface RH" Mildew Risk Scale":

The effect of local cooling (the 'BC' lines) can be translated to surface RH variations by using the local slope of the RH contours in the region of BC. Unless the lines BC are excessively long, that slope will be similar to the slope at 'B'. These slopes have been derived directly from a psychrometric chart. They are given in Table 1, which shows that the local room temperature does not have a strong influence, but the RH does. Since values of RH around 80% are considered to be the most critical, a representative scaling factor (of 5 %RH/°C) can for simplicity be chosen near that point.

| Room Temperature °C | Room RH % 60 | 70 | 80 |
|---|---|---|---|
| | Scaling Factor, %RH increase per °C decrease | | |
| 14 | 3.7 | 4.4 | 5.0 |
| 16 | 3.6 | 4.4 | 5.0 |
| 18 | 3.6 | 4.4 | 4.8 |
| 20 | 3.6 | 4.4 | 4.8 |

**Table 1. Gradient of RH contours, giving conversion factors from temperature change to Surface RH**

The effect of the local TI value on the local surface RH can now be estimated. Using Eqn (3) with the value of 5 %RH/°C from Table 1, it can be seen that:-

$$\begin{aligned} \Delta RH &= 5*(T_i - T_s) \\ &= 5*(T_i - T_o + T_o - T_s) \\ &= 5*(T_i - T_o)*(1 - (T_s - T_o)/(T_i - T_o)) \\ &= 5*\Delta T*(1 - TI) \qquad (4) \end{aligned}$$

where: $\Delta RH$ = increase in surface RH, %
$\Delta T$ = indoor - outdoor temperature difference

## 4. Derivation of Surface RH Factors

We can now construct a series of factors to represent changes in the surface RH for each of the processes listed in Section 3.

### 4.1 Space Heating:

The result of indoor heating is to lower the indoor relative humidity. The effect on surface RH is represented in Table 2 below, derived directly from a psychrometric chart, for three outdoor humidities.

| | | Mean Indoor - Outdoor Temperature °C | | | | | |
|---|---|---|---|---|---|---|---|
| Outdoor RH% | Mean outdoor Temp. °C | 4 | 6 | 8 | 10 | 12 | 14 |
| | | Indoor RH Value | | | | | |
| 100 | 4 - 16 | 77 | 67 | 59 | 51 | 45 | 39 |
| 90 | 4 - 16 | 69 | 60 | 52 | 47 | 41 | 37 |
| 80 | 4 - 16 | 61 | 54 | 48 | 42 | 37 | 32 |

**Table 2. Indoor RH with space heating alone**
( normal outdoor for New Zealand should be taken as RH 90%)
( the values vary only about ~±1 with outdoor temperature over 4 - 16°C)

### 4.2 Surface Cooling Factors:

(a) Effect of Insulation Value

The indoor surface temperature on average is affected by both surface and total R-Values. The effect is described in Eqn (5). The rated R-Values for walls are taken as, typically:-

| | | |
|---|---|---|
| R-Value | Uninsulated | 0.4 $m^2$ °C/W |
| | Reflective insulated | 0.9 $m^2$ °C/W |
| | Bulk insulated | 1.5 $m^2$ °C/W |

The inside surface resistance varies with conditions. The standard value (for R-value rating, NZS 4214) is 0.09 $m^2$ °C/W (7), and the actual value usually ranges between that and 0.12$m^2$°C/W (7). For the present purpose we use 0.10 $m^2$°C/W.

The Temperature Index at the wall surface is:-

$$TI = \frac{T_s - T_o}{T_i - T_o} = \frac{T_s - T_i + T_i - T_o}{T_i - T_o} = \frac{R - R_s}{R} \qquad (5)$$

where: R = actual local total R-Value (= Rr - 0.10 + Rs)
Rr = rated R-Value (with Rs = 0.10)
Rs = actual local surface resistance

| Description | R-Value $m^2$ °C/W | TI |
|---|---|---|
| Uninsulated | 0.4 | 0.75 |
| Reflective | 0.9 | 0.89 |
| Bulk insulated | 1.5 | 0.93 |
| Super insulated | 2.5 | 0.96 |

**TABLE 3a Temperature Index TI for insulated walls under standard conditions**

| Insulation condition | Indoor - Outdoor Temperature Difference °C | | | | | |
|---|---|---|---|---|---|---|
| | 4° | 6° | 8° | 10° | 12° | 14° |
| Uninsulated, R = 0.4 | 5 | 7.5 | 10 | 12.5 | 15 | 12.5 |
| Reflective, R = 0.9 | 2.2 | 3.3 | 4.4 | 6 | 7 | 8 |
| Bulk insulated, R = 1.5 | 1.4 | 2.1 | 3.8 | 3.5 | 4 | 5 |
| Super insulated, R = 2.5 | 0.8 | 1.2 | 1.6 | 2 | 2.4 | 3 |

**TABLE 3b. ΔRH attributable to R-Value, with standard surface coefficient**
( using Equation 4 and Table 3a )

(b) Location Effect

Data summarised in Ref. 4 shows the effect of location within a room as being expressible as a change of apparent inside surface resistance. This makes it relatively easy to incorporate the effects of corners, and shielding by furniture, into calculations by use of Equation (5):-

| **Location** | | **Apparent Local Surface Resistance** $m^2$ °C/W | **Mean R-Value** $m^2$ °C/W | | | |
|---|---|---|---|---|---|---|
| | | | 0.4 | 0.9 | 1.5 | 2.5 |
| | | | **TI Values** | | | |
| Heat flow direction, | Up | 0.1 | 0.75 | 0.89 | 0.93 | 0.96 |
| | Horizontal | 0.12 | 0.71 | 0.87 | 0.92 | 0.95 |
| | Down | 0.17 | 0.64 | 0.82 | 0.89 | 0.93 |
| Upper corners | | 0.25 | 0.55 | 0.76 | 0.85 | 0.91 |
| Lower corners | | 0.34 | 0.47 | 0.70 | 0.80 | 0.88 |
| Shielded areas | | 0.50 | 0.38 | 0.58 | 0.74 | 0.83 |

**Table 4a. Apparent local indoor surface resistances & TI values for some typical site conditions**

Table 4a is an extension of Table 3a. Using the surface coefficients of Table 4a, surface RH values comparable to those in Table 3b can be recalculated as in Table 4b for each insulation case.

| | | Indoor - Outdoor Temperature °C | | | | | |
|---|---|---|---|---|---|---|---|
| | | 4 | 6 | 8 | 10 | 12 | 14 |
| R-Value | Location | ΔRH | | | | | |
| R = 0.4 | Ceiling | 5 | 7.5 | 10 | 12.5 | 15 | 17.5 |
| | Wall | 6 | 9 | 12 | 15 | 17 | 20 |
| | Floor | 7 | 11 | 14 | 18 | 22 | 25 |
| | Upper cnr | 9 | 14 | 18 | 23 | 27 | 32 |
| | Lower cnr | 11 | 16 | 21 | 27 | 32 | 37 |
| | Shielded | 12 | 19 | 25 | 31 | 37 | 43 |
| R = 0.9 | Ceiling | 2.2 | 3.3 | 4.4 | 5.5 | 7 | 8 |
| | Wall | 2.6 | 4 | 5 | 7 | 8 | 9 |
| | Floor | 3.6 | 5 | 7 | 9 | 11 | 13 |
| | Upper cnr | 5 | 7 | 10 | 12 | 14 | 17 |
| | Lower cnr | 6 | 9 | 12 | 14 | 18 | 21 |
| | Shielded | 8 | 13 | 17 | 21 | 25 | 29 |
| R = 1.5 | Ceiling | 1.4 | 2.1 | 2.8 | 3.5 | 4 | 5 |
| | Wall | 1.6 | 2.4 | 3.2 | 4 | 5 | 6 |
| | Floor | 2.2 | 3.3 | 4.4 | 5.5 | 7 | 8 |
| | Upper cnr | 3 | 5 | 7 | 8 | 9 | 11 |
| | Lower cnr | 4 | 6 | 8 | 10 | 12 | 14 |
| | Shielded | 5 | 8 | 10 | 13 | 15 | 18 |

**TABLE 4b . ΔRH attributable to location effect** ( using Equation 4 and Table 4a )

(c) Vertical Temperature Gradient

Consider the wall cavity first. Tests to determine the effects of any vertical temperature gradient generated in the cavity are described in Appendix 2.

From Appendix 2 it can be seen that the TI values for this case were:-

at top of a midwall cavity, TI = 0.9
at bottom of a midwall cavity, TI = 0.8
at bottom of the lowest cavity, TI = 0.72

At the bottom of a (midwall) cavity, the TI value of 0.8 instead of 0.87 would give a larger local increase in ΔRH than the Table 4 value. This value, less the original Table 4 value, is given in Table 5(a) as a further increment:-

| | Indoor - Outdoor Temperature difference °C | | | | | |
|---|---|---|---|---|---|---|
| | 4° | 6° | 8° | 10° | 12° | 14° |
| | ΔRH | | | | | |
| ΔRH at bottom of cavity | 1.4 | 2 | 3 | 3 | 4 | 5 |

**Table 5(a). ΔRH from cavity-induced vertical temperature gradient (midwall)**
( in addition to the "wall" value in Table 4b )

Open wall cavities without reflective insulation have more radiant heat transmission, and less than half of the total heat flow is convective (c.f. 90%-95% for reflective cavities). It would be expected that vertical gradients would be related to the convective heat flux. The convective part of the heat flux in reflective cavities for the same overall temperature difference across the wall is calculated as 2-3 times that for nonreflective cavities, depending on the thermal resistance of the remainder of the wall. Thus the vertical temperature gradient in uninsulated walls would be 30%-50% of the value in Table 5a.

There are also vertical temperature gradients in the occupied room space, and these could be expected to have an effect on the surface RH values. However little data on the vertical moisture distribution in real spaces in houses is available Only two cases have been properly measured and both showed a higher moisture content near the floor than near the ceiling. Whilst this may be explainable as a consequence of the usual temperature gradient which could cause extra drying to the ceiling, the situation is not clear. For the present we ignore any vertical gradient in the room.

(d) Bottom Edge Chilling

This refers to the externally-induced bottom edge chilling from enhanced exposure to outside cooling. This effect might in principle occur in any wall, but is much more likley in walls on cantilevered bottom plates which extend over the line of the outer foundations. However, if bulk insulation was installed in the cavity this cooling can only reach the skirting region by conduction, principally via one corner only of the bottom plate. When the cavity is open, convective air movement can carry this cooling into the cavity, and distribute it further up the back of the lining. The process has been observed in occupied houses with reflective insulation, causing skirting temperatures to drop, typically to approximately midway between indoor and outdoor temperatures.

This condition has been estimated from the temperature map in Figure 4, Appendix 2, by assigning a temperature just below the bottom plate as equal to the cold side temperature 6.9 °C. This is equivalent to that of the bottom plate of a real panel. The coldest surface temperature, at the skirting, would be expected to drop from 19.4 °C to 18.2 °C, based on the expected downward thermal resistance of the bottom plate; viz, the TI value would be (18.2 - 6.9)/(22.5 - 6.9) = 0.72. The local increase in surface RH over the Table 4 value is given in Table 5b.

| | Indoor - Outdoor Temperature, °C | | | | | |
|---|---|---|---|---|---|---|
| | 4° | 6° | 8° | 10° | 12° | 14° |
| | ΔRH | | | | | |
| At bottom of cavity | 3 | 4.5 | 6 | 7 | 9 | 11 |

**Table 5(b). ΔRH From externally induced bottom edge chilling (at skirting)**
( in addition to the "wall" value in Table 4 )

(e) Thermal Inertia

In this section we estimate the effect of thermal inertia, mainly in the bottom plate. This effect would clearly not be confined to reflective insulated walls, but is included here for completeness to give an indication of the size of this effect.

The thermal response times of the non-frame region of lightweight walls is in the order ½ - 1 hour. The response time of the frame regions, effectively ~ 120 mm thick, is longer, perhaps 1 - 2 hours. The influence of thermal inertia is indicated therefore by the amount of (early morning) warming that is likely to take place at skirting level over ½ - 1 hour.

No general survey data is yet available. One site case has been recorded showing an early morning indoor air temperature rise near floor level of 4 °C/h, whilst the temperature rise rate at skirting level was 1.5 °C/h. The transient behaviour was largely over in 2 - 3 hours, and the vapour pressure in the room increased relative to the skirting by a maximum of 0.5 - 1 mbar for about half of that period.

This is thought to be approaching as large a change as is likely to be met. It implies that only small condensation rates would be possible, of the order 2 $g/m^2.h$, for a few hours.

(f) Thermal Bridging

Many forms of construction show some degree of thermal bridging. Equation 5 offers a way of dealing with local cooling from thermal bridging, by way of the TI value. The TI value is known for some structures and could be found for many more, perhaps by routine observation during insulation tests on structures.

Some TI values were reported for instance in (8) for steel-framed panels. With typical linings and lightweight claddings, uninsulated walls with no thermal break were reported as having a TI of 0.46. When insulated (with R1.7 insulant) but with no thermal break, the TI value was ~0.61, rising to ~0.68 when a thermal break was provided. The best TI values obtained were around 0.77. The significance of these values can be seen by comparison with Table 4b. No values were reported for foil-insulated walls.

### 4.3 Effect of Vapour Permeance

The hypothesis that the presence of vapour barriers may lead to higher indoor vapour pressure has been examined using computer simulation as described in Appendix 1, for a common house construction type which has been seen to experience mildew growth.

This simulation concluded that, at 0.4 airchanges/h and 5kg/day moisture release, the internal vapour pressure in the room would be increased from about 1.5 mbar to about 3 mbar by addition of a vapour barrier.

There is a limited amount of field evidence on indoor vapour pressure values in houses in New Zealand. In 1976 (6) Trethowen reported a mean excess of 1.9 mbar from 8 houses without vapour barriers, but this data derives from measurements by pen recorders of uncertain accuracy. Estimates made by Cunningham (11), indicated that the mean excess vapour pressure in the houses he surveyed, all without vapour barriers, was typically 1-2 mbar. In two commercial tests in houses with vapour barriers, values of 3.1 and 4.2 mbar have been observed.

The increase in the local surface RH values attributable to vapour pressure increase is given in Table 6, which is derived directly from the psychrometric chart. There is some uncertainty about the actual vapour pressure excess.

| | Indoor Temperature $^{o}C$ | | | | | |
|---|---|---|---|---|---|---|
| | 4 | 6 | 8 | 10 | 12 | 14 |
| Excess VP, mbar | $\Delta$RH Value | | | | | |
| 1 | 9 | 8 | 7 | 6 | 5 | 4.5 |
| 2 | 18 | 16 | 14 | 12 | 10 | 9 |
| 3 | 27 | 24 | 21 | 18 | 15 | 13.5 |
| 4 | 36 | 32 | 28 | 24 | 20 | 18 |

NB Excess VP values of 1-2 mbar are typical for "normal" construction
Excess VP values of 3-4 mbar are considered typical with vapour barriers

**Table 6. $\Delta$RH attributable to indoor moisture gain**

## 5. Quantitative Comparison of Mildew Risk Effects

The foregoing data can now be applied to test the mildew risk with particular i constructions, such as with reflective-insulated walls. A brief example ncluding this case is given below:-

Example. To find the mildew risk at the bottom corner skirting of three houses with different insulation levels:-

| | |
|---|---|
| Uninsulated | $R_r$ = 0.4 $m^2{\cdot}{}^oC/W$ |
| Reflective Insulated | $R_r$ = 0.9 $m^2{\cdot}{}^oC/W$ |
| Bulk Insulated | $R_r$ = 1.5 $m^2{\cdot}{}^oC/W$ |

The outdoor mean winter temperature is 8°C, and mean indoor temperature is 16°C, i.e. the mean temperature difference is 8°C.

| | Uninsulated | Reflective Insulated | Bulk Insulated |
|---|---|---|---|
| Room RH from heating alone (Table 2) | 52 | 52 | 52 |
| Moisture Gain Factors (see Table 6) | 14 | 21 - 28 | 14 |
| Mean room RH | 66 | 73 - 80 | 66 |
| Surface cooling effect ( see Eqn. 5) | | | |
| bottom corner (Table 4b) | 21 | 12 | 8 |
| wall temp gradient(Table 5a) | 1 | 3 | - |
| bottom edge chill (Table 6) | 2 | 6 | - |
| Surface RH at skirting | 90 | 94-101 | 74 |

**Table 7. Calculation of surface RH values at skirting for three houses.**

Several issues are immediately presented by Table 7. The mildew risk at skirtings is predicted to be slightly higher (at 99%) than outdoors (90%) for uninsulated walls. The predicted risk (at 95-100%) is no better in reflective insulated walls than in uninsulated walls. The predicted risk is low (at 74%) with bulk insulated walls.

It can be seen in Table 7 that the mean indoor RH is forecast at 66% without vapour barrier and 73% - 80% with vapour barrier, under these conditions.

## 6. Conclusions

A quantitative method of assesing mildew growth risk at a number of key locations in houses has been presented, using a surface RH scale.

This method may be suitable for application in Handbook form, as heat loss estimates are now. It illustrates in a single, clear scale the size and direction of each individual factor affecting mildew risk. It makes strong use of the "Temperature Index" (TI), which is a normalised indoor surface temperature parameter, introduced by Sasaki (8) 1971. The TI is amenable to routine assessment, for instance during thermal insulation rating tests.

The method has been applied to exterior walls of three insulation grades. It indicates that under "typical" winter conditions, space heating to 16°C mean would produce a general indoor RH of 66% without vapour barriers, and 73 - 80% with vapour barriers. However with surface cooling effects the surface RH would be over 95% for uninsulated or reflective insulated walls, but only about 74% for bulk insulated walls. Thus the risk of mildew growth near skirtings is indicated as slightly higher than that outdoors for uninsulated walls or reflective insulated walls, and absent for bulk insulated walls under these conditions. This indicates that reflective-only insulation produces no significant decrease in the risk of mildew growth, with the insulation advantage over uninsulated walls being offset by the vertical temperature gradients and higher indoor vapour pressures.

Where heating is inadequate, there are high risks of direct condensation on the wall linings, especially at skirting level. Because of the presence of the vapour barrier action with reflective insulation, any moisture so condensed can not dry off outward through the wall and must dry inwards only. This effect has not been included in the above estimates.

Factors not yet addressed in this work are dynamic issues of the influence of the thermal inertia of the wall structure and incubation time of mildew, and special influences such as high-tech construction materials.

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## APPENDIX 1. Effect of Vapour Permeance

The likely influence of the vapour barrier action which reflective insulation also provides, has been examined by computer simulation. This work was carried out as a prelimary investigation February 1991, and based on a room space in which all surfaces, roof, wall and floor were of identical construction. The work is summarised below.

The simulation was done on an unvalidated program, CAVITY (version 9.2), developed independently for exploratory purposes.

CAVITY is a lumped simulation model which deals with typical framed walls. It allows for default and user specification of all material types, dimensions, thermal and vapour flow properties, hygroscopic properties, coatings, climate conditions, moisture emission, and ventilation rates both indoors and in cavities. It presents results graphically as a plot of moisture contents and surface mildew risk, against time, for periods up to 600 days.

The present study simulated just two construction types:

(a) typical fibre-cement plank clad, timber-framed wall, with reflective-backed linings; and

(b) a wall identical in all respects except that the reflective insulation was treated as completely vapour permeable.

A comparison of the two should indicate the effect of having a vapour barrier present or absent.

Simulation was begun at mid autumn or earlier. The simulated mildew risk and mean element moisture content appeared to stabilise within 1-2 months of the start of winter. The climate was represented by a synthetic function based on superimposed sinusoids with yearly, weekly and daily components of appropriate magnitude. The indoor climate was taken as 5°C above outdoors, except when it fell below defined allowable minima.

Simulations for the two wall types were made for a number of values of minimum indoor temperatures, from 12°C to 18°C, and for various room ventilation rates from 0.2 air change/h to 1.0 air change/hour.

The typical room excess vapour pressures and lining moisture contents were recorded for each run. The lining m.c. is taken as the mildew risk indicator, with the EMC (equilibrium moisture content) value corresponding to >85% RH in steady isothermal conditions being taken as the criterion for mildew growth.

The results of these simulations are set down in Figure 3, which shows the room excess vapour pressure and mildew risk zone derived as above, overplotted as a function of mean room ventilation rate, for walls with and without vapour barriers.

For Wellington region the minimum indoor temperature with zero heating is typically around +10°C. Thus Figure 3 suggests that mildew will not be found if the ventilation rate exceeds 0.5 - 0.8 air change/h, depending on the average moisture emission rate. Extra heating reduces the minimum ventilation rate required to prevent mildew occurring. Clearly, higher moisture emission also raises both room vapour pressure and mildew risk.

The general conclusions were:-

- risk of mildew growth on walls is substantially increased if a vapour barrier is present
- the internal vapour pressure in the room in substantially increased if a vapour barrier is present
- the above conclusions also apply for very cold winters (e.g. USA) but may be detected only if the risk of mildew growth is high.

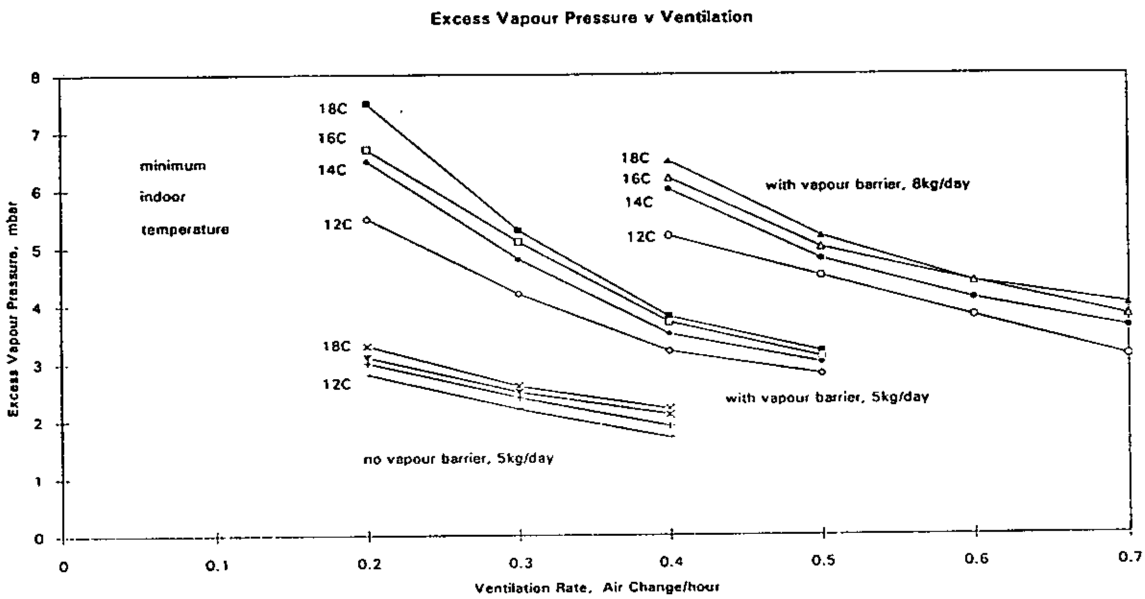



**Figure 3. Predicted indoor vapour pressures, from stepwise simulation**

The increase in the local surface RH values attributable to vapour pressure increase is given in Table 6, which is derived directly from the psychrometric chart. In reality, there is some uncertainty about the actual vapour pressure excess.

## APPENDIX 2. Vertical Temperature Gradient

To quantify the amount of vertical temperature gradient likely in the cavities of reflective-insulated walls, tests were carried out at BRANZ in 1993, as summarised below.

A 1600 mm wide x 1200 mm high wood-framed panel was constructed from 90 x 45 mm dry pinus radiata, and clad on the cold side with 10 mm gypsum plasterboard over black building paper. It was clad on the warm side with 10 mm gypsum plasterboard with reflective foil facing the cavity. The test cavity was 420 mm high centre-to-centre, 1000 mm wide centre-to-centre, and was "guarded" on all edges with other cavities of the same construction though of different height or width.

The cavity and warm-side surface were fitted with an array of 32 Cu/Con thermocouples to show the cavity, frame and warm-side temperatures on the vertical centreline of the cavity. Warm - and cold-side air temperatures were included, and were 22.5 °C and 6.9 °C during the period of observation, with vertical temperature difference of less than 0.2 °C on either side over the entire panel height of 1200 mm.

All thermocouples were individually calibrated for relative offset and for steam point output. No variation in sensitivity was found, and individual offsets were used to correct readings later. The panel was run to steady-state conditions (> 12 hours), and the cavity and surface temperatures were then recorded at 1 minute intervals over 10 - 15 minutes.

The temperature profiles were recorded as indicated in Figure 4, which shows temperature contours for the cavity. There was indeed a significant vertical temperature gradient generated on the warm-side surface. Under the test conditions of 22.5 °C warm side, 6.9 °C cold side:-

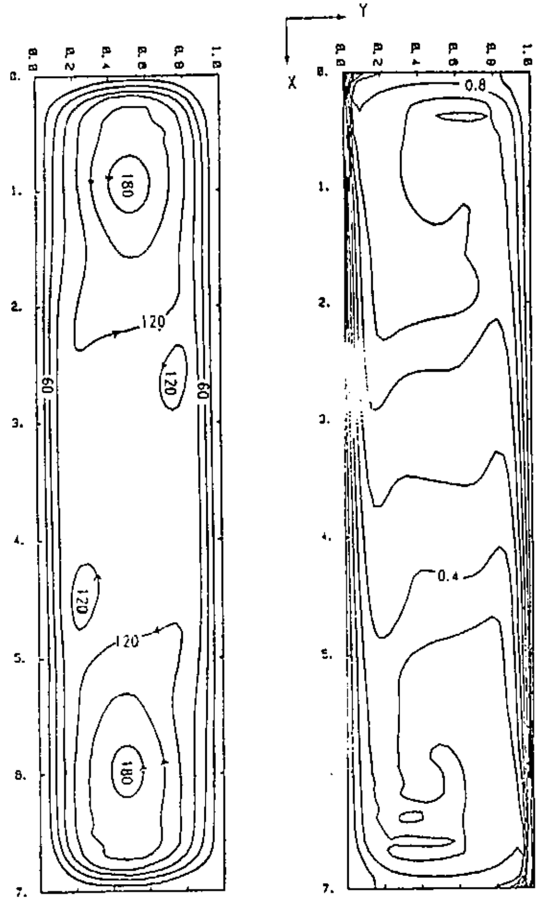
- the nominal warm-side surface temperature of 20.9° C for this panel occurred only at the very top edge of the cavity; viz, the TI value in this region was (20.9 - 6.9)/(22.5 - 6.9) = 0.9, close to that estimated in Table 4a,
- the lowest warm-side surface temperature of 19.4 °C occurred at the bottom edge of the cavity, 3.1 °C colder than the warm side temperature; viz, the TI value in this region was (19.4 - 6.9)/(22.5 - 6.9) = 0.8 ( 0.1 lower than at the top of the wall).

These conditions were obtained for a test cavity "guarded" on all sides; viz, they correspond to the condition in a mid-section of wall.

| | Indoor - Outdoor Temperature, °C | | | | | |
|---|---|---|---|---|---|---|
| | 4° | 6° | 8° | 10° | 12° | 14° |
| | ΔRH | | | | | |
| At bottom of cavity | 4 | 6 | 8 | 10 | 12 | 14 |
| (increase over top of cavity) | (3 | 4.7 | 6 | 7.5 | 9 | 10.5) |

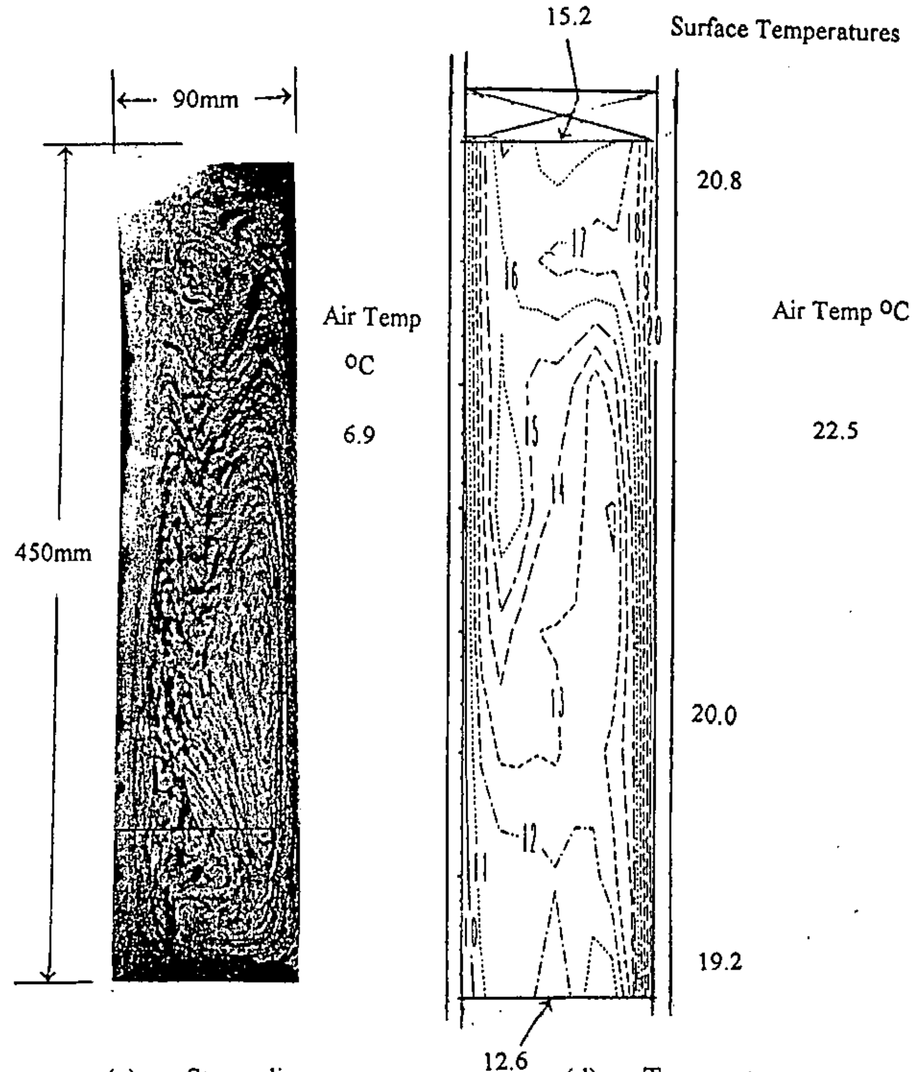
**Table 5. ΔRH from cavity-induced vertical temperature gradient (midwall)**

( from Equation 3 and TI values as above )




(a) Streamlines (b) Temperatures

Typical Laboratory results for Isothermal wall temperatures
($Gr_T$ = 2*106, GrC=0, Ref 8)




(c) Streamlines (d) Temperatures

Measured Values for Foil-Insulated Wall with ~ Isothermal External Air Temperatures.

Figure 4 - Streamlines and temperature contours in a wall cavity.

The cavity flow conditions were determined subsequently, after the thermocouples had been removed. The cavity was blacked out and cross-illuminated at one cross section only, of 10 - 20 mm width. Marker particles of a metaldehyde "snow" were released into the cavity, and viewed via a mirror at the end of the cavity. The air velocity in each area can be found from the length of trace left by individual particles. These results are also illustrated in Figure 4, and the inferred maximum circulation velocity was ~ 50 mm/s.

An anatomy of mildew risk
with reflective insulation.
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