Feature

# Hygrothermal Failure Case Study: Fergusson School

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**INSULATED ROOFS THAT** are insulated above the purlins and contain a vapor-control layer (VCL) are a new technology in New Zealand, and these types of roofs need more in-depth hygrothermal modeling than was required for traditional (insulation at the ceiling level) vapor-leaky roof systems that were used in the past. Over the last decade, the addition of more insulation into traditional roof systems has become a trend in New Zealand as owners aim to increase occupancy comfort, improve health, and reduce energy consumption. However, such efforts may lead to condensate problems in the roof layers, as discussed in more depth in later sections. New legislation has been recently proposed[1] to further increase the amount of insulation required in roof assemblies. The proposal is driven mainly by the desire to reduce energy consumption, but this type of requirement has the potential to exacerbate interstitial condensate problems. The prospect of such condensate problems makes the modeling and correct use of model boundary conditions by designers all the more urgent.

In New Zealand, the Ministry of Education (MoE) is responsible for the care and performance of state-owned schools. The MoE periodically releases a document entitled *Designing Quality Learning Spaces (DQLS),*[2] which sets out the performance requirements for their school buildings. Among other parameters, the DQLS gives guidelines for some environmental settings such as air changes per hour (ACHs) and internal temperature levels of various school rooms based on room usage. These parameters are useful in analyzing the hygrothermal performance of new builds, assuming that the correct boundary conditions (discussed later) have been selected.

Hygrothermal modeling consists of predicting the flow of heat and moisture through a building, with the aim of avoiding or mitigating problems such as mold growth, corrosion, and interstitial condensation. To provide an accurate model, certain boundary conditions must be determined, including the internal and external temperatures, internal and external relative humidity, moisture load, risk level, and ACHs. These parameters can then be modeled by either steady-state or dynamic analysis techniques.

The internal air temperature is either measured or assumed as a model parameter, and the temperature depends on location and season. Some studies use the thermostat setpoint and assume this is the air temperature that is maintained in the building. Assumed values are typically in the range 20°C–25°C (68°F–77°F),[3,4] while observed values range from 16°C–25°C (61°F–77°F).[5-7] These values come from a wide range of climates, including New Zealand, the US, Estonia, Finland, and the Arctic. The MoE advises that the internal air temperature should be 18°C (65°F) in general learning environments and 16°C (61°F) for gyms, and it has other conditions for specialist learning environments such as laboratories and art rooms.

External air temperatures show a much wider range than internal temperatures, from −5°C (23°F) to +35°C (95°F) in New Zealand. This is, of course, because inhabitants do not manipulate the external air temperature. These values show a stronger dependence on air temperature and season. Generally, hygrothermal models are based on mean monthly temperature data collected over a significant period of time. The weather information used in this paper came from the World Meteorological Organization (WMO) and the lower quartile mean monthly temperature has been used. The lower quartile value was used to allow for solar gain and cooling by the longwave radiation phenomenon as outlined in the European standard *Hygrothermal Performance of Building Components and Building Elements—Internal Surface Temperature to Avoid Critical Surface Humidity and Interstitial Condensation—Calculation Methods* (EN ISO 13788).[8]

The relative humidity also depends on location and season, with winter values ranging from 27%[5] to 70%[7] in some parts of Europe, and summer values from 52%[5] to 80%.[7] Relative humidity can also be assumed from the climate zone (Glaser method). In New Zealand, the ranges for the three main cities (Auckland, Wellington, and Christchurch) vary throughout the year from 77% to 89%, 80% to 87%, and 72% to 87%, respectively. The MoE in New Zealand sets a target of 65% for learning environments.[2]

The most difficult parameter to determine (in the authors' opinion) is the ACH. This can range from 0.05 for a sealed and unvented attic (Kayello 2013)[7] to 10 for a highly ventilated attic.[3] Values around 0.1 to 1 are more typical for living areas,[3-5] and simulations run up to 15.[7] The MoE describes 4 ACH as "ideal"; achieving that value would require mechanical ventilation. The ministry considers anything under 2.5 ACH to be poorly ventilated but notes that levels can go as low as 0.75 ACH in classrooms that rely only on natural ventilation.[2] This wide range of choices means there is a risk of picking an inappropriate ACH value unless a somewhat conservative approach is taken. Natural ventilation seems improbable in winter climates as the ventilation relies on windows being left open during class time. However, natural ventilation (along with minimal mechanical ventilation) has become popular in New Zealand schools due to the reduced cost of mechanical plant to control the internal environment.

The moisture load depends not only on the ACH value but also on the type of building,[3,9] the use of the room,[10] and the number of inhabitants, as well as the season and location. Moisture load values are typically lower in the summer than in the winter, with summer values around 0.3–2.5 g/m$^3$ (0.000019–0.000156 lb/ft$^3$) and winter values around 2–6 g/m$^3$ (0.000125–0.000375 lbs/ft$^3$). Moisture generation rates can be around 7–15 kg/d (15–33 lb/d),[4,6] which would be considered high for most applications. More specifically, for people's normal range of activity, various researchers have reported generation rates of 0.9 kg/d (2 lb/d), 1.25 kg/d (2.8 lb/d), and 0.96–2.4 kg/d (2.1–5.3 lb/d).[11]

The European standard EN ISO 13788[8] adopts a system that assigns a "humidity class" based on the internal moisture excess load, with designations ranging from 1 to 5. The moisture loads for humidity classes 1 to 5 are 2, 4, 6, 8, and 10 g/m$^3$ (0.00062 lb/ft$^3$), respectively. The formula to calculate the humidity class is as follows:

$$V = G_m / nV_s \tag{1}$$

where $G_m$ is the moisture production rate, $n$ is the air change rate, and $V_s$ is the volume of the space under scrutiny.

Common building uses that are associated with the different humidity classes are shown in **Table 1.** To add some conservatism to a hygrothermal design, the EN ISO 13788 suggests picking the class above that which has been calculated.

To date, the focus has been on comparing computer models with small-scale tests or making improvements to the existing software models based on assumed boundary conditions. Many of the previously cited studies are pure modeling efforts that do not include comparisons to experimental results. While pure modeling studies can be valuable, experimental validation of modeling results is crucial. With better estimation of boundary conditions, software models can make better predictions, and the amount of redundancy used in the model can be highlighted. This work collects detailed information on a real failure and then manipulates the current model until the same field-observed failure is recorded. The observed failure in this study occurred at a school, and as such the New Zealand MoE guidelines[2] have been used to ascertain certain boundary conditions.

**TABLE 1. Humidity classes and associated building uses.**

| Humidity class | Building |
|---|---|
| 1 | Unoccupied buildings, storage of dry goods |
| 2 | Offices, dwellings with normal occupancy and ventilation |
| 3 | Buildings with unknown occupancy |
| 4 | Sports halls, kitchens, canteens |
| 5 | Special buildings, e.g., laundry, brewery, swimming pool |

***Source:*** *Excerpted from EN ISO 13788 Table A.1.*[8]

## ROOF BUILDUP

The building that is the subject of this paper was situated in Upper Hutt, Wellington, New Zealand. The building was north facing, situated in climate zone 4,[1] corrosion zone 2,[12] and at an altitude of 49 m (161 ft) above sea level. The building was lightweight construction with timber framing, brick veneer, and a metal skin roof (**Fig. 1**). Internally, the walls were lined with plasterboard and had a suspended tile ceiling.

The building is composed of 10 main rooms, which are a combination of classrooms, common areas, and changing rooms (**Fig. 2**). The classrooms were approximately 9.5 m × 7.5 m (31 ft × 25 ft) in floor area and 2.4 m high (8 ft).

The roof and ceiling were constructed as shown in **Figure 3.** The main components were acoustic tile, ceiling insulation, plenum with steel purlins at approximately 1,200 mm (4 ft) centers, wire netting, underlay, and a metal profiled roof.

## FIELD OBSERVATIONS

Shortly after the completion of the building in the winter months, condensate was noted forming on the steel purlins in all of the classrooms (**Fig. 4**). There were also signs of organic matter growing on the building wrap (**Fig. 5**). It is expected, based on previous investigation by the authors, that the black growth is *Stachybotrys chartarum,* a common mold found in New Zealand (and elsewhere in the world) in building enclosure layers.

It was estimated that the condensate drops were greater than 150 g/m$^2$ (0.031 lb/ft$^2$) as it was apparent that runoff occurred from this upper region and manifested in drops on the lower edge of the purlin (**Fig. 6**). It was also noticed that the pipe support bolt and nut showed signs of corrosion, which is a sign of high moisture load occurring in the plenum. **Table 2** replicates a guide on droplet density and its implications from EN ISO 13788.

One additional aspect of this failure was that after the organic growth problem was observed,

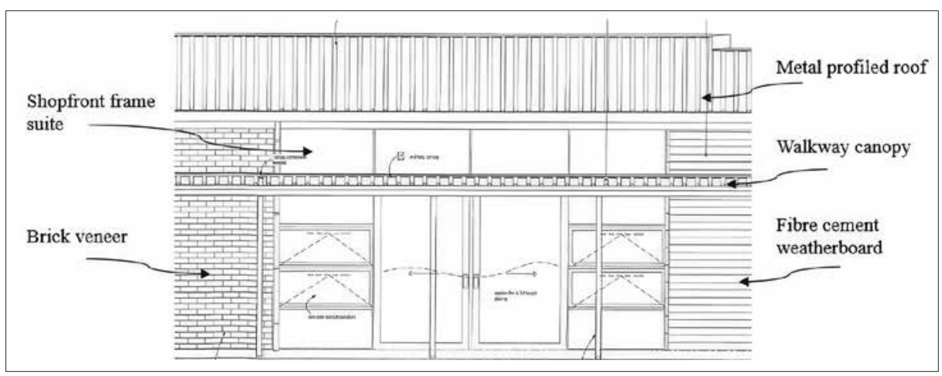



**Figure 1.** *General construction of the building enclosure.*

**Figure 2.** *General layout of the classrooms.*

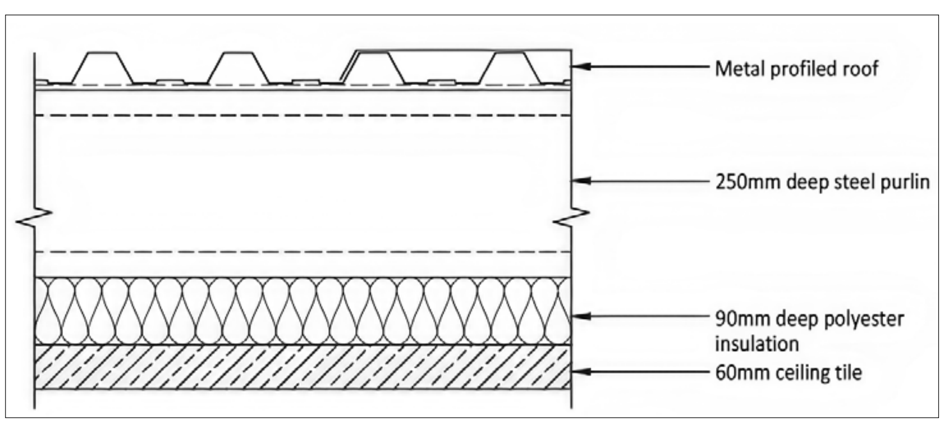



**Figure 3.** *Roof/ceiling assembly. Note: 1 in. = 25.4 mm.*

**Figure 4.** *Condensate forming on purlins.*

**Figure 5.** *Visible organic growth on the building wrap.*

vent holes were installed into the soffits in hopes that the additional venting would eliminate the moisture upon which the organisms were feeding. Unsurprisingly, the extra venting brought in more moisture-laden air during the winter nights and the problem worsened. Other researchers[13] have highlighted similar venting problems in the past.

## MODELING

The modeling software was JPA Designer version 6.04a1 019 produced by JPA TL Ltd., based in the United Kingdom. JPA Designer assesses the risk of interstitial condensation using the steady-state method defined in ISO 13788:2012,[8] which uses mean monthly temperatures and relative humidities to assess the risk of interstitial condensation over a 12-month period. The program uses the Glaser method for predicting the interstitial condensation risk of an assembly. The method provides a general assessment of suitability of the construction; however, it does not address air movement within the construction, and it does not take account of the effects of capillary moisture transfer. It is the authors' opinion that one-dimensional steady-state analysis is sufficient when dealing with roof assembly design to achieve a pragmatic design technique.

In this study, we calibrated the boundary conditions in the software model to get the same condensate effect at the same layer as the observed failure. We then analyzed the required boundary conditions to determine whether they were realistic. The boundary conditions required to get the observed condensate were as follows:

**Figure 6.** *Droplet formation on the steel purlin and rust evident on services bolt and nut.*

**TABLE 2. Droplet density manifestation on vertical and sloped surfaces.**

| Moisture density | Result |
|---|---|
| **Vertical surfaces** | |
| < 30 g/m$^2$ (0.006 lb/ft$^2$) | A fine mist which does not run or drip |
| 30–50 g/m$^2$ (0.006–0.010 lb/ft$^2$) | Droplets form and begin to run down vertical surfaces |
| 51–250 g/m$^2$ (0.01–0.051 lb/ft$^2$) | Large drops form and begin to run down |
| **Sloping surfaces** | |
| 70 g/m$^2$ (0.014 lb/ft$^2$) | Will run down a 45-degree slope |
| 150 g/m$^2$ (0.031 lb/ft$^2$) | Will run down a 23-degree slope |
| > 250 g/m$^2$ (0.051 lb/ft$^2$) | Drops form and drip from horizontal surfaces |

***Source:*** *Excerpted from EN ISO 13788.*[8]

- Moisture load: Humidity Class 1 in accordance with EN ISO 13788[8] (< 0.002 kg/m$^3$ [0.000124 lb/ft$^3$]). This load equates to an ACH of 2.2, which is based on 20 students (0.9 kg/d [2 lb/d] each) and a room volume of 171 m$^3$ (6,039 ft$^3$).
- The risk level was set to average, which means the minimum mean monthly external temperature is used rather than a risk-applied safety factor. (For schools, the applicable risk safety factor would generally be a 1 in 10-year probability factor as suggested in EN ISO 13788.)
- It was assumed that the metal roofing was "vapor leaky" due to side lap gaps (0.3 mm [1/64 in.]) as suggested by Piñon and LaTona,[14] which gives a vapor resistance of 67 MNs/g (0.26 US Perms).

The results for the winter analysis (the time of the year when the problem occurred) for the failed traditional roof are shown in **Figure 7.** In the graph shown in Figure 7b, the solid line (interface temperature) and dotted line (corresponding dew point temperature) touch at the interface between the plenum and the mesh/airspace layers. The predicted moisture and accumulation are shown in Figure 7c. The modeling indicates that condensate occurs from May through to December before the drying potential of the system starts in the summer months. The model predicts that a significant amount of condensate would occur and would form droplets of water that would drip from a horizontal surface (i.e., the upright face of the purlin), which correlates well with the observations.

## SCENARIO MODELING

With the model calibrated to the observed failure and boundary conditions, we then used the same conditions to run the following five scenarios:

1. No extra insulation directly above the insulated ceiling tile in a traditional roof
2. More insulation in a traditional roof
3. An insulated roof with the original failed roof setup
4. Less insulation in the ceiling plenum with an insulated roof
5. More insulation in the ceiling plenum with an insulated roof

Additionally, we modeled the original case using a design in accordance with the EN ISO 13788 guidelines,[8] including safety factors (risk factor set to 1 in 10 years and Moisture Class 3), to determine whether a problem could have been predicted at the initial design stage.

Depictions of each of the scenarios are shown in **Figure 8. Table 3** presents the findings for the six scenarios with comparisons between peak and annual accumulations, and the difference between the vapor and saturated pressures at the point where the vapor pressure first significantly drops. This point is at the interface between the airspace and the steel mesh for the traditional roofs and between the VCL and foil-faced insulation for insulated roofs.

### Scenario 1: What Would Happen if Less Insulation Were Used?

This scenario showed no annual accumulation of condensate, but some condensate occurred from May to August before drying out by December. More accumulation occurred in this scenario than in the original case (1.14756 kg/m$^2$ [27 lb/ft$^2$]) compared to 0.72183 kg/m$^2$ [17 lb/ft$^2$]). Condensate would form droplets of water that would drip from a horizontal surface.

### Scenario 2: What Would Happen if More Insulation Were Used?

More insulation at the ceiling layer resulted in less accumulation of condensate forming than in the original case. Condensate occurred between May and December before drying out.

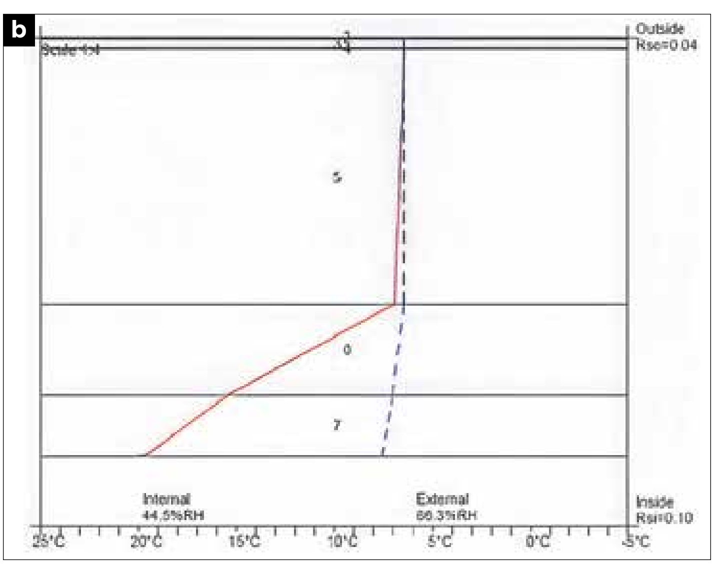
### Scenario 3: What Would Happen if an Insulated Roof Were Used?

The buildup of this system matched the original amount of ceiling insulation used in the traditional roof assembly. No condensate was predicted in this case. There is a clear gap between the vapor and

**a**

| | Thickness (mm) | Thermal Conductivity (W/mK) | Thermal Resistance (m²K/W) | Vapour Resistivity (MNs/gm) | Vapour Resistance (MNs/g) |
|---|---|---|---|---|---|
| Outside surface resistance | - | - | 0.040 | - | - |
| MSR Topdeck 0.55BMT with vapour gaps | 0.6 | 3.003 | 0.000 | 111667 | 67.00 |
| Underlay | - | - | - | - | 7.00 |
| Steel mesh | 1.1 | 0.000 | 0.000 | - | 0.00 |
| Airspace | 250.0 | - | 0.160 | - | 0.00 |
| Insulation | 90.0 | 0.032 | 2.800 | 5.00 | 0.45 |
| Ceiling tile | 60.0 | 0.043 | 1.400 | 6.83 | 0.41 |
| Inside surface resistance | - | - | 0.100 | - | - |
| **Total thickness** | **401.7mm** | | | | |

**b**




**c**

**Condensation is occuring at the following layers interfaces:-**
Interface 1 : Steel mesh / Airspace

| Month | Int (C°) | Int (%RH) | Ext (C°) | Ext (%RH) | Interface 1 Gc (Kg/m²) | Ma (Kg/m²) |
|---|---|---|---|---|---|---|
| Jan | 20.00 | 59.50 | 13.40 | 80.30 | 0.00000 | 0.00000 |
| Feb | 20.00 | 61.90 | 13.60 | 83.00 | 0.00000 | 0.00000 |
| Mar | 20.00 | 58.10 | 12.60 | 81.90 | 0.00000 | 0.00000 |
| Apr | 20.00 | 54.00 | 10.90 | 83.30 | 0.00000 | 0.00000 |
| May | 20.00 | 49.50 | 8.80 | 84.90 | 0.05325 | 0.05325 |
| Jun | 20.00 | 46.10 | 6.90 | 87.00 | 0.22564 | 0.27889 |
| Jul | 20.00 | 44.50 | 6.30 | 86.30 | 0.24190 | 0.52080 |
| Aug | 20.00 | 44.30 | 6.50 | 84.90 | 0.18612 | 0.70692 |
| Sep | 20.00 | 45.50 | 7.70 | 81.80 | 0.01492 | 0.72183 |
| Oct | 20.00 | 48.00 | 9.00 | 80.90 | -0.11198 | 0.60986 |
| Nov | 20.00 | 50.70 | 10.30 | 80.10 | -0.23383 | 0.37603 |
| Dec | 20.00 | 56.00 | 12.20 | 80.40 | -0.37845 | 0.00000 |

Gc = Monthly moisture accumulation per area at an interface
Ma = Accumulated moisture content per area at an interface

Peak accumulated moisture content per area at interface (Ma) = 0.72183 Kg/m²

Annual moisture accumulation = 0.00000 Kg/m²

**Figure 7.** *Condensation analysis of a traditional roof: (a) roof buildup; (b) solid line representing the interface temperature and the dotted line the corresponding dew point temperature; (c) condensate peak and annual accumulation values.*

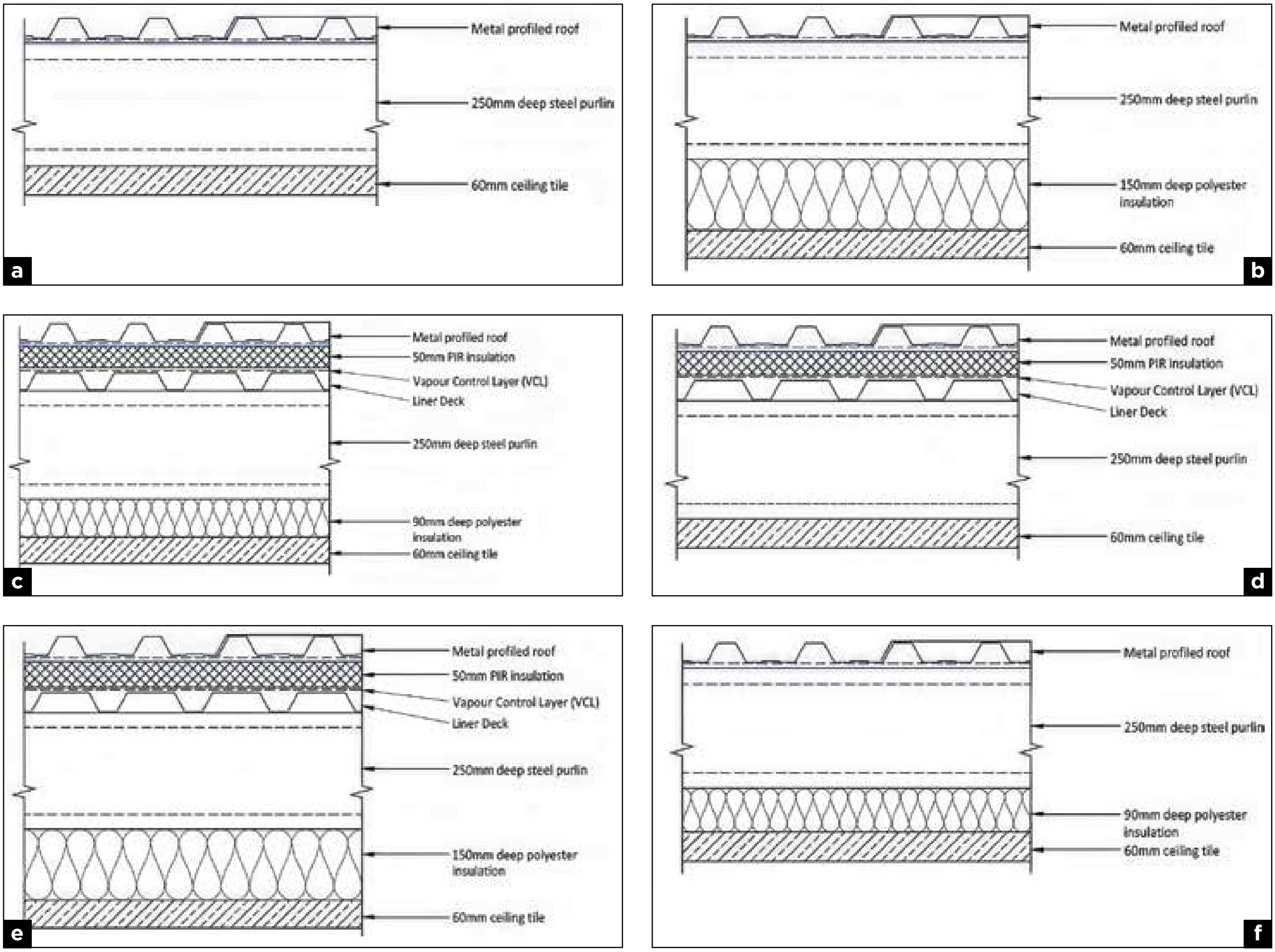



**Figure 8.** *Modeled scenario sections: (a) No extra insulation directly above the insulated ceiling tile in a traditional roof; (b) More insulation in a traditional roof; (c) An insulated roof with the original failed roof setup; (d) Less insulation in the ceiling plenum with an insulated roof; (e) More insulation in the ceiling plenum with an insulated roof; (f) original case including safety factors.*

saturated pressures at the VCL-to-insulation interface. The difference between these pressures is 0.52 kPa (0.075 psi).

### Scenario 4: What Would Happen if Less Ceiling Insulation Were Used with the Insulated Roof?

No condensate was predicted but more redundancy between the vapor and saturated pressures was noted than the previous design. The difference between the vapor and saturated pressures was 0.8 kPa (0.12 psi).

### Scenario 5: What Would Happen if More Ceiling Insulation Were Used with the Insulated Roof?

No condensate was predicted, but the difference between the vapor and saturated pressures (0.44 kPa [0.064 lb/ft$^2$]) was less than that in the last two designs.

### Scenario 6

A design was done with safety factors switched back on for the original traditional roof buildup and assuming a "design-office" approach that shows the required conservatism for a dependable design (i.e., commonly used boundary conditions). The results of this analysis indicated that monthly and annual condensation would occur. These results would be considered a failure, and the system would need to be redesigned.

## RESULTS

The model predicted the failure at the correct layers and with the correct type of condensate (i.e., drips forming on a horizontal surface). We showed, for traditional roofs, that insulation in the form of tiles or ceiling batts needs to be checked for condensate failure as the subtraction of insulation below the VCL can reduce the redundancy of the system.

We also found that when an insulated roof is adopted, the greater the amount of ceiling insulation used in the system is, the higher the potential for interstitial condensate is. This finding is the reverse of the scenario for traditional roofs.

## DISCUSSION

Based on evidence from the real-life example presented herein, it is evident that an interstitial condensate problem exists under certain circumstances in some buildings in New Zealand. However, the problem can be predicted with some degree of confidence by using observational boundary conditions and the hygrothermal analysis method described in ISO 13788.[8]

If the right boundary conditions are not chosen, the design could be flawed. Choosing the right conditions can be challenging because not all of the variables are readily available to designers, and assumptions must therefore be made. One strategy to get around the uncertainty is to use conservative values for the boundary conditions. However, care must be

**TABLE 3. Comparison of the modeled systems.**

| Scenario | Roof type | Extra glass-fiber insulation thickness below the vapor control layer, mm | Polyisocyanurate insulation thickness above the vapor control layer | Peak accumulation, kg/m² | Annual accumulation, kg/m² | Δ vapor and saturated pressures, kPa |
|---|---|---|---|---|---|---|
| 1 | Traditional roof | 0 | 0 | 1.14756 (27.2 lb/ft²) | 0 | 0 |
| 2 | Traditional roof | 150 (6 in.) | 0 | 0.56170 (13.3 lb/ft²) | | 0 |
| 3 | Insulated roof | 90 (3.5 in.) | 50 (2 in.) | 0 | 0 | 0.52 (0.075 psi) |
| 4 | Insulated roof | 0 | 50 (2 in.) | 0 | 0 | 0.8 (0.12 psi) |
| 5 | Insulated roof | 150 (6 in.) | 50 (2 in.) | 0 | 0 | 0.44 (0.064 psi) |
| 6 | Traditional roof SF | 90 (3.5 in.) | 0 | 12.3487 (293 lb/ft²) | 12.3487 (293 lb/ft²) | 0 |

taken not to be too conservative as that could add unnecessary cost to the building.

The ISO 13788 technique can be problematic with excess conservatism due to unknown variables. Some potential problems include the Humidity Class bands (which are wide), weather data accuracy, and the blunt method (as JPA uses a one-dimensional steady-state analysis technique). However, from an engineering point of view, it is far easier to control and manage the steady-state variables when compared to the more chaotic dynamic analysis method. JPA offers easy viewing of the boundary condition assumptions, which are readily changeable and not "hidden from view." The JPA outputs can readily be used in other software programs to further analyze different aspects of design such as organic growths and the corrosion criterion.

One critical variable that is hard to define occurs with the natural ventilation case and involves determining the ACH value of a particular room of interest. Determining the correct ACH is critical to the design, but it is difficult to estimate without having on-site testing. One method for predicting ACH is based on the dimensions of operable windows and doors into a room.[15] This method is fairly easy to use, but the accuracy of the technique is undetermined. Nevertheless, the technique gives a good basis for an experienced designer to choose a suitable ACH.

Careful design is required to check the ceiling/roof assembly when using traditional and insulated roofs, particularly if ceiling insulation (insulation below the VCL) is used. The analysis presented in the modeling section indicates that for insulated roofs, the inclusion of ceiling insulation must be checked to address the potential risk of condensate.

The analysis of failures helps us understand how the failure occurred and what boundary conditions are pertinent to cause the failure. However, a hygrothermal predictive design needs to incorporate redundancy (i.e., safety factors). One method would be to use a class above the theoretically required class when using the EN ISO 13788 technique (refer to Table 1). When using the same method, adjusting the risk factor from 1 to 10 years to 1 to 15 years would also allow for some conservatism. Ultimately, the best method when attempting predictive designs is to comparatively analyze different combinations of the ceiling/roofing layers. By designing using this method, a "good, better, best" hierarchy of design can be established.

To date, other researchers have presented models based on assumptions, which leads to bias, albeit unintentional. The work presented herein takes an actual failure case to ascertain the values used for boundary conditions. This information is valuable in determining how accurate a design might be when compared to a real-life scenario.

Roof hygrothermal designs should include not only the roof but also the ceiling assemblies, and the designer must carefully choose boundary conditions that are appropriate for the intended building use. It is also important to allow for some conservatism in a predictive design, and preferably to assess comparative designs of multiple system arrangements.

## CONCLUSION

Hygrothermal boundary conditions were found forensically by studying the case of an interstitial condensate building failure. The specific boundary conditions used to predict the failure were the moisture load of Humidity Class 1 (< 0.002 kg/m³ [0.00012 lb/ft³]), which equates to an ACH of 2.2; the minimum mean monthly external temperature with the risk factor set to zero; and vapor resistance of the metal roofing set to 67 MNs/g (0.26 US Perms). Different scenarios were then analyzed using these boundary conditions to see where the problems, if any, lay. We found that care is required when designing traditional roofs because condensate can occur very soon after installation. This issue is particularly a problem when plenum insulation is used in an attempt to increase the *R*-value of a roof/ceiling system.

Our analysis found that removing plenum insulation causes more condensate to occur in traditional roof cases. Conversely, adding insulation to a traditional roof at the ceiling layer decreases the amount of condensate forming but does not completely stop the interstitial condensate from occurring. Certainly, a reduction in moisture load will inhibit organic growth, but it will not eliminate the problem. The investigation showed that one way to resolve the organic growth problem was to adopt an insulated roof philosophy.

An insulated roof can resolve the interstitial condensate problem by incorporating a VCL, which changes the ratio of vapor to saturated vapor pressure. Calculations showed that reducing ceiling insulation in an insulated roof system improves the redundancy in the system. Conversely, increasing ceiling insulation reduces the redundancy and can cause condensate if too much insulation is added below the VCL layer. Modeling indicated, with an appropriate balance of insulation above and below the VCL layer, the surface condensate problem could be eliminated.

Once the appropriate boundary conditions were established, a determination of suitable conservatism could be applied to the hygrothermal analysis. The appropriate degree of conservatism is important so as not to overdesign a ceiling/roof and, in doing so, add extra cost to the project. However, of equal importance, a designer must have some confidence that their proposed design will work from an interstitial point of view. Based on the analysis presented herein, it is reasonable to conclude that the method adopted in the JPA software, which is modeled on the ISO 13788,[8] produces a conservative but appropriate analysis to help ensure that interstitial condensate is avoided in the ceiling/roof layers.

An initial hygrothermal design analysis for a proposed system before it is built can help prevent a condensate problem in the future. However, boundary conditions must be carefully chosen to get realistic results. A comparative analysis of different assemblies may help designers choose the most appropriate design.

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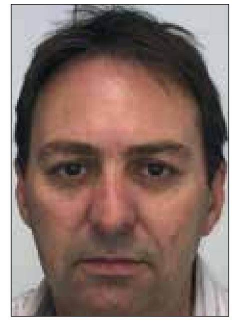

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