Initial guidance on the moisture design of large-span roofs for schools

BRANZ Discussion Document

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PURPOSE

This report summarises the current knowledge available to provide guidance when designing large-span school roofs to minimise or prevent condensation damage within the roof space. The information contained within the document is based on BRANZ research, discussions with the industry, reference to overseas practice and other relevant overseas literature.

A design approach is proposed that is believed to be conservative and will be refined further as research results become available.

Knowledge gaps in the control of roof moisture still exist in New Zealand, and it is anticipated that this document will assist the industry to identify and fill these knowledge gaps. There is an opportunity for BRANZ, the Ministry of Education and industry representatives to work together to further understand roof space moisture and communicate the findings through regular updates to this document.

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1. INTRODUCTION

An increasing number of moisture-related problems are being observed in the roofs of modern school buildings. In particular, the phenomenon of aggravated thermal bridging (ATB) has been identified and researched at BRANZ. In the case of ATB, designs that may have previously been effective have failed because of an increased moisture load in the roof space. ATB is an example of the wider issue of heat, air and moisture control in structures. Although the specifics of ATB are discussed in this document, it is the general approach to effective moisture control that is the main focus.

Construction practices and the way we have used buildings have changed over the years. Concerns about energy efficiency have led to increased levels of insulation, and although New Zealand buildings are not compelled to meet an airtightness requirement, buildings are often built to higher levels of airtightness than before. Modern schools are making use of large open-plan spaces that offer flexible learning environments but are quite different to the schools of the previous decades. In the past, even if not specifically provided by vents, ventilation would have naturally assisted with the removal of moisture from both the occupied space and the roof space. The ventilation would have come from cracks and gaps that were present all over the building envelope. This is no longer the case. The ratio of the building surface area to the building volume has changed so that any infiltration is likely to be much less significant in large open-plan enclosures. We need to be actively thinking about the control of indoor moisture from the occupied space and roof ventilation in our designs.

This document provides a structured approach to the moisture control design of roofs and the analysis necessary to evaluate a particular construction. The focus is necessarily on roofs, but much of the guidance can be applied to other building elements. The design pathway is intended to be a conservative approach to be used in lieu of the knowledge and research gaps being filled. There are active research projects at BRANZ on the topic of roof moisture, and more work is planned for the future. When the role of ventilation in the occupied and roof spaces is better understood and controlled, the design approach is expected to become less conservative.

2. CONDENSATION AND FAILURE CRITERIA

2.1 Interstitial versus surface condensation

If air comes into contact with a surface that is below the dewpoint temperature of the air, it will deposit moisture as condensate. If sufficient condensate forms, this may run down vertical surfaces or drop from horizontal surfaces.

In the case of indoor surface condensation, the condensate forms on the innermost layer of the building envelope – the walls or the windows. Although this is unsightly and could lead to mould growth if it persists for long enough, this form of condensation is likely to be a less severe issue than interstitial condensation. In general, to avoid surface condensation, a building with a high indoor humidity will need its surfaces to be at a higher temperature than those of a low-humidity building.

Interstitial condensation relates to condensation within the structure itself. When migrating through the structure, the air may strike a surface that is below its dewpoint temperature. Depending on the structure and the interior conditions, this condensation may accumulate and cause damage to the structure with very little evidence at the interior or exterior of the building. Since the condensate is often unseen and could be in part of the structure that is more sensitive to moisture, interstitial condensation is likely to be a more serious problem than surface condensation.

2.2 Failure criteria

To analyse a structure effectively, it is necessary to have criteria to assess it against. The source of the moisture in roof condensation problems will generally be the indoor air, so the relevant clause of the New Zealand Building Code is E3 *Internal moisture*. This states the following functional requirement:

> Buildings must be constructed to avoid the likelihood of–
> (a) Fungal growth or the accumulation of contaminants on linings and other building elements; and
> (b) Free water overflow penetrating to an adjoining household unit; and
> (c) Damage to building elements being caused by the presence of moisture.

At the current time, no specific methods have been adopted for verifying compliance with the performance of NZBC clause E3.

Despite the lack of a specific failure criteria in New Zealand, various criteria exist overseas for assessing the condensation risk of structures. In this section, ASHRAE 160-2009 *Criteria for Moisture-Control Design Analysis in Buildings* and BS 5250:2011 *Code of practice for control of condensation in buildings* are discussed and may be of interest for further reading.

2.2.1 ASHRAE 160-2009 *Criteria for Moisture-Control Design Analysis in Buildings*

The need for ASHRAE 160-2009 arose from increased use of computer-based modelling tools and because relatively little attention had been paid to the choice of appropriate inputs and boundary conditions. Another reason cited for the standard was that many of the current recommendations and rules for moisture control are not based on a consistent set of underlying assumptions, i.e. the design loads.

The standard applies to new buildings as well as additions to and retrofits and renovation of existing buildings and includes all types of buildings, building components and materials. The aim of the standard is to specify performance-based design methods for predicting, preventing, mitigating or reducing moisture damage depending on climate, construction type and system operation.

ASHRAE 160-2009 has the following criteria for minimising mould growth when the corresponding running average temperatures are between 5°C and 40°C:

a) 30-day running average surface RH<80%

b) 7-day running average surface RH<98%

c) 24-hour running average surface RH<100%.

The ASHRAE 160-2009 criterion for prevention of corrosion is the same as a) above. In the case of both fungal growth and corrosion, the standard states that material-specific criteria should be used if they are available. TenWolde (2011) provides a more detailed discussion of ASHRAE 160-2009 including some of the likely changes for future revisions.

2.2.2 BS 5250:2011 *Code of practice for control of condensation in buildings*

This British standard guides designers to use the methods described in BS EN ISO 13788:2012,[1] which has the following criteria to avoid condensation problems:

- Over the coldest month in the year, the average relative humidity at internal surfaces does not exceed 80%.
- Any interstitial condensation that occurs in winter must evaporate during the following summer to prevent year-on-year accumulation.
- The risk of degradation of materials should be based on the maximum level of condensate that might occur.

The actual method in BS EN ISO 13788:2012 is a 1-D steady-state diffusion model known as the Glaser method. This is not particularly suited for use with roofs and is not recommended within this ATB work (see Methods of Analysis).

BS 5250:2011 has the following caveat about the methods in BS EN ISO 13788:2012:

> Designers should be aware that BS EN IS0 13788 considers only the risks arising from diffusion of water vapour through the building fabric; it does not take account of the much greater risk of condensation occurring as a result of air leakage, which transports water vapour through gaps, joints and cracks in the building fabric.

BS 5250:2011 also states:

> … while the method is useful for comparing the performance of different structures, it does not provide an accurate prediction of moisture conditions within the structure under service conditions. More advanced methods, which are standardized in BS EN 15026, are available.

[1] BS EN ISO 13788:2012 *Hygrothermal performance of building components and building elements. Internal surface temperature to avoid critical surface humidity and interstitial condensation. Calculation methods*

BS EN 15026:2007[2] is similar to ASHRAE 160-2009 in that it provides guidance on the use of more complex heat, air and moisture transport simulation software, but there are no specific failure criteria in the document.

2.2.3 WUFI-Bio

Mould growth can also be assessed using WUFI-Bio, which is a postprocessor for the WUFI range of software (see WUFI) that has been created to estimate mould growth on surfaces. It is designed to take transient input data from WUFI and run it against a hygrothermal model of a mould spore.

WUFI-Bio was developed by the biology section at the Fraunhofer Institute in Germany and has been benchmarked against measurement data from their laboratories. It is a more advanced indicator of mould growth risk than the single criteria in ASHRAE 160-2009, in that it can better take account of transient effects and properties of the substrate and mould species. It allows for selecting a substrate class based on its ability to support mould (i.e. to what extent the mould can use the substrate for food) and also allows the selection of the type of mould.

These are powerful features, especially as the differences between mould growth rates on steel and across mould species timber can vary widely.

The typical output of WUFI-Bio is a time series plot of mould growth rate, with a simple traffic light system of pass/borderline/fail.

[2] BS EN 15026:2007 *Hygrothermal performance of building components and building elements. Assessment of moisture transfer by numerical simulation*

3. ROOF DESIGN – CHOOSING THE RIGHT CLIMATES

Buildings such as schools are likely to have a large internal moisture load, and the tendency is for moisture to move from inside the structure outwards. By estimating the amount of moisture generated within the building, a designer can calculate the vapour pressure difference between indoors and outdoors. This difference in vapour pressure, in conjunction with the nature of the structure, largely determines the risk of condensation occurring. To perform an appropriate analysis of a structure, it is therefore necessary to apply suitable indoor and outdoor climates as boundary conditions.

3.1 Indoor climate

In general, the most reliable data for the indoor climate would be measured data (see box). In lieu of measured data, several overseas guidelines and standards contain information about indoor climates that may be useful to designers in New Zealand. For example, BS 5250:2011 and ASHRAE 160-2009 have very similar methods for calculating a suitable indoor climate.

In recent years, there has been rapid development of relatively affordable and compact wireless data loggers. These devices can be easily deployed to obtain information about the temperature and humidity of the structure in question.

These two devices both measure relative humidity and temperature. The one on the left connects to a wireless network allowing real-time monitoring. The one on the right stores the data so it can only be interrogated when the device is docked to a computer.

ASHRAE 160-2009 has a simplified method, intermediate method and full parametric calculation options for determining the indoor vapour pressure. In the simplified method, the indoor humidity is a function of the daily average outdoor temperature. The intermediate method takes account of moisture generation and ventilation of the occupied space. For example, for buildings without dehumidification or air conditioning, the internal vapour pressure is calculated as:

$$P_i = P_{o,24} + \frac{c\dot{m}}{Q}$$

where

P_i	=	indoor vapour pressure (Pa)
$P_{o,24}$	=	the 24-hour running average outdoor vapour pressure (Pa)
c	=	1.36×10^5 Pa.m^3/kg
$\dot{m}$	=	design moisture generation rate kg/s
Q	=	design ventilation rate m^3/s

Moisture generation rates are provided for residential designs, but for other occupancies, the moisture load should be *appropriate for the intended use of the building.* Ventilation rates are also suggested for buildings without a designed ventilation system.

With regard to temperature, ASHRAE 160-2009 suggests that the temperatures should be the designed value. If that is not specified, the indoor temperature is a function of the outdoor temperature (typically the 24-hour running average outdoor temperature plus 2.8°C).

BS 5250:2011 has a similar equation to the one above for calculating the internal vapour pressure and includes a range of suggested moisture generation rates for different household activities. A moisture generation rate that may be useful in the design of school roofs is 70 g/h per person corresponding to people carrying out office work. However, there are likely to be other significant moisture loads at the same time.

For non-residential buildings, BS 5250:2011 employs 'humidity classes' corresponding to the use of the building. Schools are not explicitly mentioned but would probably be considered a class 4 building. The vapour pressure difference across the building envelope can then be calculated as a function of the monthly mean outdoor temperature.

For the ATB analysis work, the internal climate was based on a limited amount of measured data from buildings with intermittent temperature control and no relative humidity control except the opening of windows. Approximate wetness classifications for the indoor environment were also used ranging from dry to very wet.

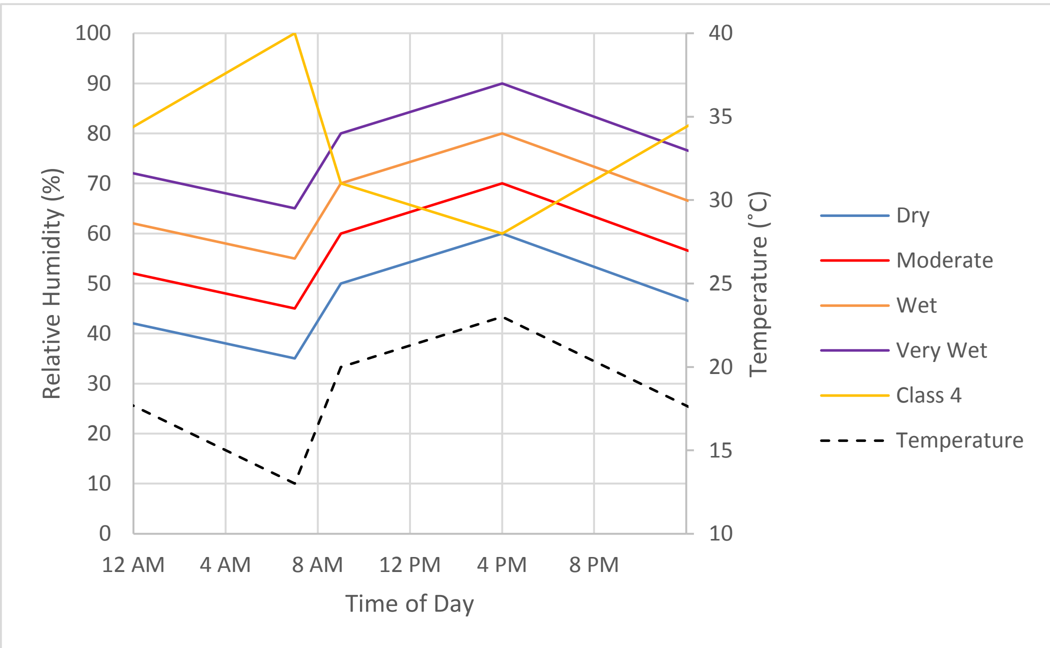


Figure 1 Humidity and temperature profiles used in ATB work compared with corresponding humidity of a class 4 building at the same temperature

The approximate humidity range of a Class 4 building in BS 5250:2011 is also shown in Figure 1. Note that this is out of phase with the humidity used in the BRANZ ATB work. The BRANZ data implies the moisture generation in the occupied space outweighs the drop in relative humidity that would normally be associated with an increase in the internal temperature.

Note also the BS 5250:2011 mentions that, if at the designed operational temperature the RH is likely to exceed 70%, it will be necessary to remove moisture from the air either by ventilation or dehumidification.

3.1.1 BRANZ work on indoor climate

In 2015, BRANZ will be initiating a project on the improved use of hygrothermal modelling software. Among the project aims is to better define the indoor environments that are representative of New Zealand buildings. Our current database of indoor climate data is incomplete, with many measurements being of short duration. This work will collate as many residential measurements as possible, both from active and historical projects.

The project also has scope to include data from schools and other institutional buildings. The outcome will be that designers will have access to more representative climate profiles than those assumed in the BRANZ ATB work.

3.2 Outdoor climate

As important as the indoor climate, the choice of outdoor climate also warrants consideration by the designer. There is still active debate in the building physics community on the use of average-case versus worst-case climate data. ASHRAE 160-2009 specifies the use of moisture design reference years that are the 10th-percentile warmest and 10th-percentile coldest years from a 30-year weather analysis. BS 5250:2011 references the use of BS 13788:2012, which is essentially the Glaser method (see Methods of Analysis), in conjunction with monthly mean climate data.

The data source recommended is from the US National Climate Data Center, which is derived from long-term averages. Long-term average data isn't necessarily ideal for moisture analysis, so BS 5250:2011 suggests correction factors to generate data for the worst climate with a return period linked to the use of the building. BS EN 15026:2007, which is also mentioned in BS 5250:2011, suggests correcting typical data by adding or subtracting 2° from the outdoor temperature and leaving the humidity unchanged. This depends on whether summer or winter condensation is likely to be the problem.

In New Zealand, NIWA generated a series of climate files for use in the Energy Efficiency and Conservation Authority's Home Energy Rating Scheme (HERS). Here, all the climate stations across the country were assessed for their suitability based on the amount and type of meteorological data collected. Then, a station was chosen as being representative of a particular region. The climate files for each location consist of 12 individual months of data, each selected to match the average distribution for that month over a decade or more. These climate files do not therefore represent worst-case data.

Most of the resultant New Zealand climate files are built into the WUFI software tool (see Methods of Analysis). For other locations, software such as Meteonorm can be used to generate climate data. Data can also be collected from the NIWA CliFlo database or from MetService.

With particular importance to roofs is the effect of solar radiation (short-wave radiation) and night-time cooling (an effect of long-wave radiation exchange – see box), so climate files should be investigated for the suitability of this data.

Solar gain

Short-wave radiation from the sun can have a pronounced effect on the temperature of the exterior surface of a building. In a roof space, this effect can lead to increased temperatures of the air and thus can assist in drying out any condensation. With porous roof claddings, the increased temperature from the solar radiation can lead to moisture being driven through the cladding material, i.e. solar-driven moisture. The degree of exposure to direct sunlight can be affected by the neighbouring buildings and terrain.

Night sky radiation

Exterior surfaces usually emit more long-wave radiation than they receive, resulting in cooling. During the day, this cooling process is more than offset by the solar gain, but at night, it can lead to a surface cooling significantly below the ambient temperature of the air.

The basic reason for the net long-wave radiation loss is that the surface emits radiation to the sky but the main gases that make up the sky are poor emitters. Water vapour, on the other hand is a much better thermal emitter, so on cloudy nights, the radiation loss is less. On clear nights, it is therefore likely that the exterior roof cladding will cool below the dewpoint temperature of the ambient air, and condensation will form on its surface. In many instances, climate files do not contain measured long-wave radiation data, so the values are estimated using other parameters such as cloud coverage, ambient humidity and ambient temperature.

4. ROOF DESIGN – CONTROLLING HEAT AND MOISTURE TRANSPORT

This section covers some general principles of the control of heat, air and moisture before discussing the types of roofs seen in modern school buildings. As stated previously, condensation will form on a surface that is below the dewpoint temperature of the surrounding air, so preventing it requires consideration of the movement of heat and moisture through a structure.

4.1 Moisture transport – the need to limit the amount of moisture in the air

Two basic transport mechanisms move water vapour through a structure – convection and diffusion. Of the two, convection is the more powerful mechanism and can move orders of magnitude more water vapour than diffusion. Convection is essentially the bulk movement of air from a high air pressure to a low air pressure, so it can be due to mechanical ventilation, passive ventilation, stack effects and buoyancy. Diffusion is the movement of water vapour from a high partial vapour pressure to a low partial vapour pressure.

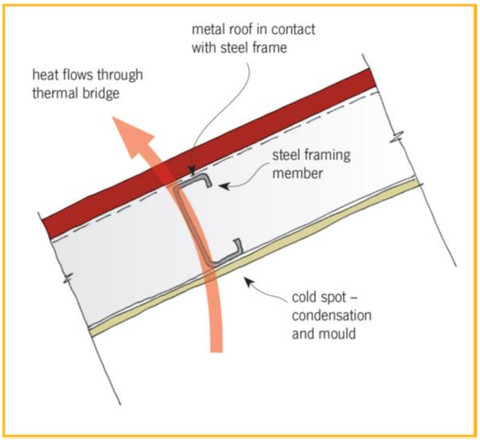
To help avoid interstitial condensation arising from diffusion, a general rule of thumb is to have the material with highest vapour resistance on the warm side of the insulation. In a cold climate, where the indoor space is heated, this would be on the inside of insulation. In a hot humid climate, where the indoor space may be severely air conditioned, the high vapour resistance material would be on the outside of the insulation. Typically, for residential construction at least, New Zealand falls between these two extremes, and this is one reason why a dedicated vapour control layer (VCL) is not normally specified. This approach is justified by the fact that interstitial condensation is rarely seen in buildings that do not have a high indoor moisture load and aren't in alpine areas.

Another general rule of thumb relates to the control of air movement – 'build it tight and ventilate right' – making the envelope as tight as practically possible and then providing dedicated ventilation. The rationale behind this is two-fold. It reduces the passage of air (and moisture) through the building envelope and enables effective HVAC design, i.e. to control the air in a particular space efficiently, you first need to contain it. To 'build tight' implies consideration of the air barrier system employed in the structure. In general, an airtight layer on the warm side of the envelope will minimise the penetration of warm moist air into the construction and so reduce the risk of interstitial condensation.

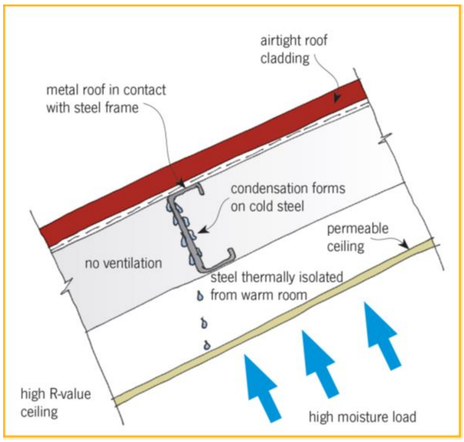
The approach whereby specific attention is given to the various control layers in the building envelope has not been largely promoted in this country. In New Zealand, the cost of such an approach may often be deemed unnecessary, but if buildings are being subjected to higher moisture loads, it at least requires consideration.

4.2 Heat transport – the need to minimise thermal bridging

It is desirable to minimise thermal bridging in the structure for both energy and moisture control reasons. In a heating environment, thermal bridges represent areas of increased heat loss and hence lead to lower surface temperatures and a higher risk of condensation. Standard thermal bridging is illustrated in Figure 2 a). Here, no attempt has been made to add a thermal break, but standard thermal bridging would also cover cases where a thermal break has been designed but not implemented correctly. For example, if insulation is draped over the purlins but then compressed when the roof cladding is installed, the compressed area may act as a thermal bridge. Figure 2 b) shows what is meant by aggravated thermal bridging. The purlin is isolated from the ceiling, so there is no direct conductive path. However, the combination of other factors shown in mean that the purlin can end up at a lower temperature than the dewpoint of the surrounding air, resulting in condensation and corrosion.



a) Standard thermal bridging



b) Aggravated thermal bridging

Figure 2 Types of thermal bridging (insulation omitted for clarity)

4.3 The use of control layers

In buildings with high indoor moisture loads, it is necessary to at least consider and perhaps provide various control layers in the structure, be it an air barrier, VCL or thermal control layer. The key to the performance of each layer is continuity, so it is recommended to consider this continuity throughout the design, construction and usage phases of the building. To help ensure continuity, it is often useful to trace each control layer on the detailed drawings. If it is not clear how continuity is to be maintained at a particular detail, improved drawings (perhaps 3D) or mock-ups should be produced. If it cannot be understood how the continuity is to be maintained by looking at the plans, it is almost certain that continuity will not be achieved during construction.

4.4 Application to roofs

Thermal considerations, moisture transport and the use of control layers are relevant to the whole building. However, the focus of this document is roofs, so only the relevant concepts are discussed here. Nevertheless, when designing the roof, it is still necessary to consider other building elements that may bypass the ceiling, such as wall cavities.

4.4.1 Different roof types and the role of ventilation

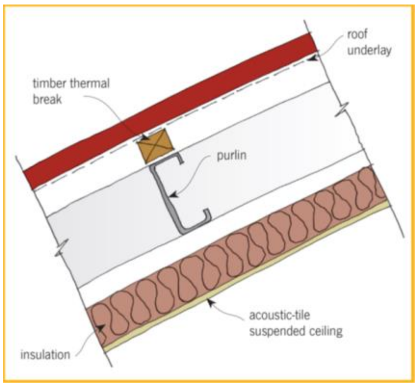
There are many categories of roofs relating to the roof pitch or the configuration of the elements that make up a roof. Unfortunately, the terminology used around the world is not always consistent. For example a 'warm' roof as described in BS 5250:2011 is a roof where the insulation follows the roofline, and a 'cold' roof is where the insulation follows the line of the ceiling. A typical New Zealand skillion roof (as show in Figure 3 a) could arguably be classed as either 'warm' or 'cold' using this definition. For the purpose of this document, a 'warm' roof is a roof where the roof decking (purlins and rafters) are on the inside of the insulation.

BS 5250:2011 provides guidance for various roof structures relating to the placement of air and vapour control layers and the role of ventilation, but it stops short of providing specific guidance for large roofs.

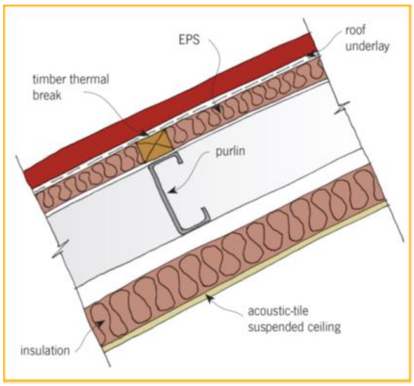
Ventilation of the occupied space is important for maintaining indoor air quality, but it can also reduce the basic moisture load that the roof has to deal with if the ventilation removes the moisture from the structure. However, if the ventilation actually moves moisture into the roof space, it has the opposite effect. Ventilation of the roof voids may be an entirely separate process to the ventilation of the occupied space but will again have the potential to remove moisture from the roof structure before it can potentially condense. BS 5250:2011 contains the general advice for roofs that ventilation should be provided underneath any air impermeable layer on the cold side of the insulation. Although BS 5250:2011 does not contain guidance on roofs with exactly the same structure as a New Zealand skillion roof, some of the examples are reasonably similar.

4.4.2 Aggravated thermal bridging roof specimens

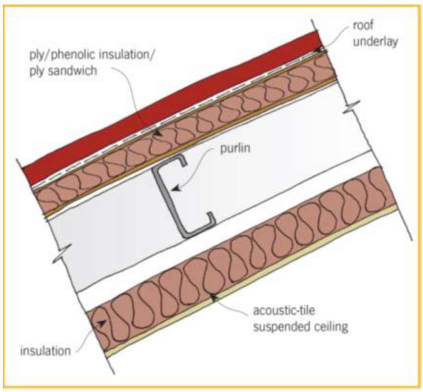
In the BRANZ ATB work, a series of roof types were investigated to understand their resistance to condensation. Four roof styles were installed on a test building in Dunedin, and the indoor climate was controlled to be the 'very wet' condition shown in Figure 1. A roof with a 'standard' thermal break at the purlins was compared with a series of roofs with various continuous thermal breaks – in simple terms, comparing a cold roof with a warm roof. The two layers of insulation depicted in our experimental roofs are mainly a result of the need to find remedial solutions to existing buildings. For new builds, a sufficiently insulated warm roof will be adequate to avoid condensation issues. Further details of the different specimens can be found in BRANZ Study Report SR289 and BRANZ Bulletin 572.



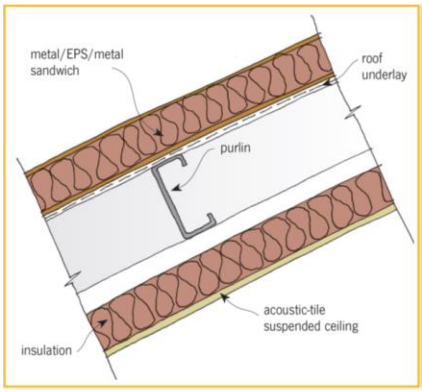
a) Timber



b) Timber and EPS



c) Plywood-lined Phenolic SIP



d) Metal-lined EPS SIP

Figure 3 Roof specimens investigated in the BRANZ ATB work

The results of the ATB work showed that the 'standard' 90 mm timber or EPS thermal break was ineffective at preventing condensation. Subsequent modelling showed this would be the case even if a more airtight ceiling was employed. The systems with continuous thermal breaks were all effective at reducing the risk of condensation and are less reliant on airtight ceilings.

A series of design graphs (see Figure 4) were produced to show the reduced condensation risk in sufficiently vented roofs with adequate insulation below the roof cladding.

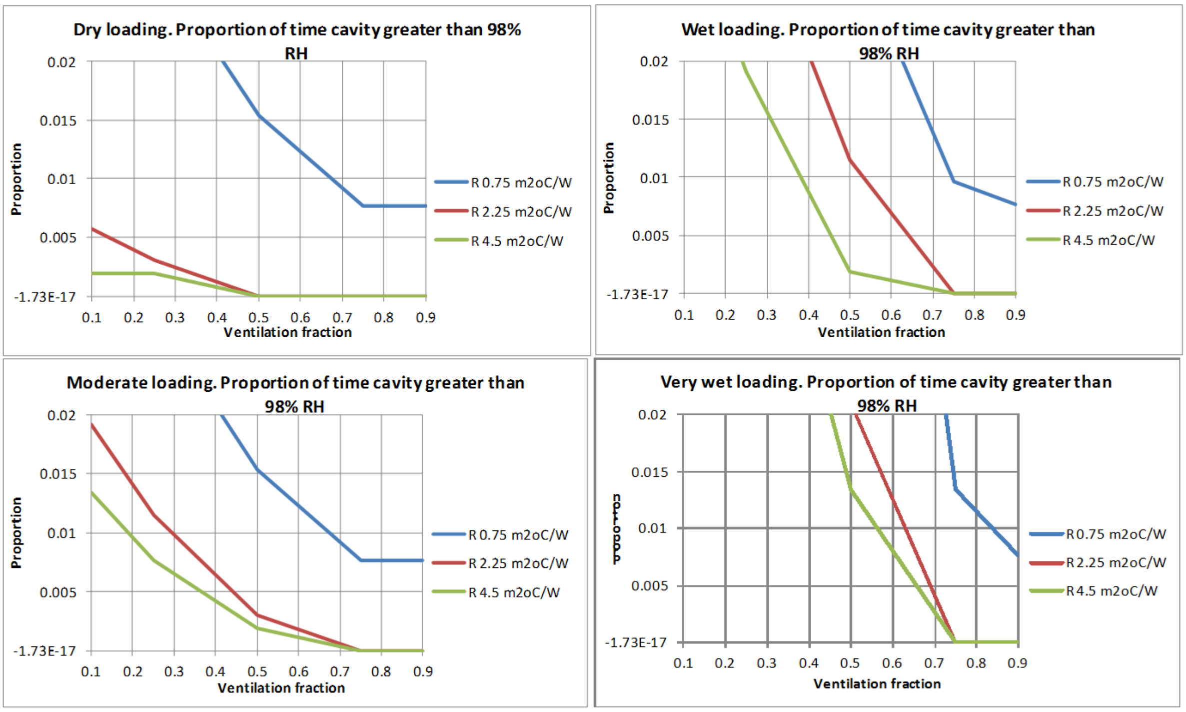


Figure 4 Sample design graphs from the BRANZ study on aggravated thermal bridging

Assuming a 'very wet' loading, the design graphs show the relative humidity will not exceed 98% at all with R2.25 insulation under the cladding and a ventilation ratio (airflow in roof void/airflow from occupied space to roof from inside) of 0.8.

In the BRANZ ATB experiments, the ventilation fraction was 0.97. This was achieved without any conscious ventilation design, such as introducing vents, and was measured with the roof ridge sealed.

5. METHODS OF ANALYSIS

It is possible to analyse certain structures using simple manual methods such as the Glaser method, and this is evidenced by their continued inclusion in international standards. However, these methods typically consider vapour diffusion only and are not suitable or recommended for use with the kind of roofs that are the subject of this document.

Issues include that these methods:

- do not account for convective moisture transport, which can dominate over the diffusion process
- do not account for moisture storage in materials
- do not account for variable moisture properties, for example, many materials have a vapour resistance that varies with relative humidity
- are one-dimensional so cannot easily take account of framing, for example
- cannot account for variable indoor and outdoor conditions (including solar radiation) particularly well.

The alternative to manual methods is to use a more complex hygrothermal simulation tool, such as WUFI. BRANZ is a collaborative partner with the Fraunhofer Institute, who created the simulation tool. BRANZ researchers have specifically added the capability to include cavity ventilation into the 2D version of the software (McNeil, 2010). The 2D analysis is often of preference in New Zealand because it allows the effect of the framing to be included. In this section, we provide a degree of guidance on the use of WUFI and describe some research work at BRANZ relating to a nodal model. The nodal model is intended to allow quick exploration of design parameters, such as the amount of ventilation in the roof space.

5.1 WUFI

WUFI is an incredibly powerful tool for designing moisture-tolerant construction assemblies, developed at the Fraunhofer Institute for Building Physics in Munich. It allows the drawing of a construction as an assembly of components and the testing of this assembly under a climate regime of one's choosing.

WUFI comes in two variants, one-dimensional, known as WUFI Pro, and two-dimensional, known as WUFI 2D. Depending on the situation being modelled, WUFI Pro may suffice. If there are thermal bridges in the construction (particularly steelwork) or significant amounts of timber, WUFI 2D is the preferred tool, as it will allow these details to be represented better. There are examples of WUFI being used incorrectly within New Zealand. Therefore, it is strongly recommended that consideration is given or guidance sought prior to using the tool.

5.1.1 General analysis procedure

A general procedure for conducting a hygrothermal simulation is shown in Figure 5. This is adapted from the process shown in ASHRAE 160-2009. For WUFI, it is also desirable to have knowledge of suitable surface transfer coefficients and the ventilation rates in any cavities being modelled.

As has been discussed in this document, there are unknowns relating to several of the steps in this process in New Zealand.

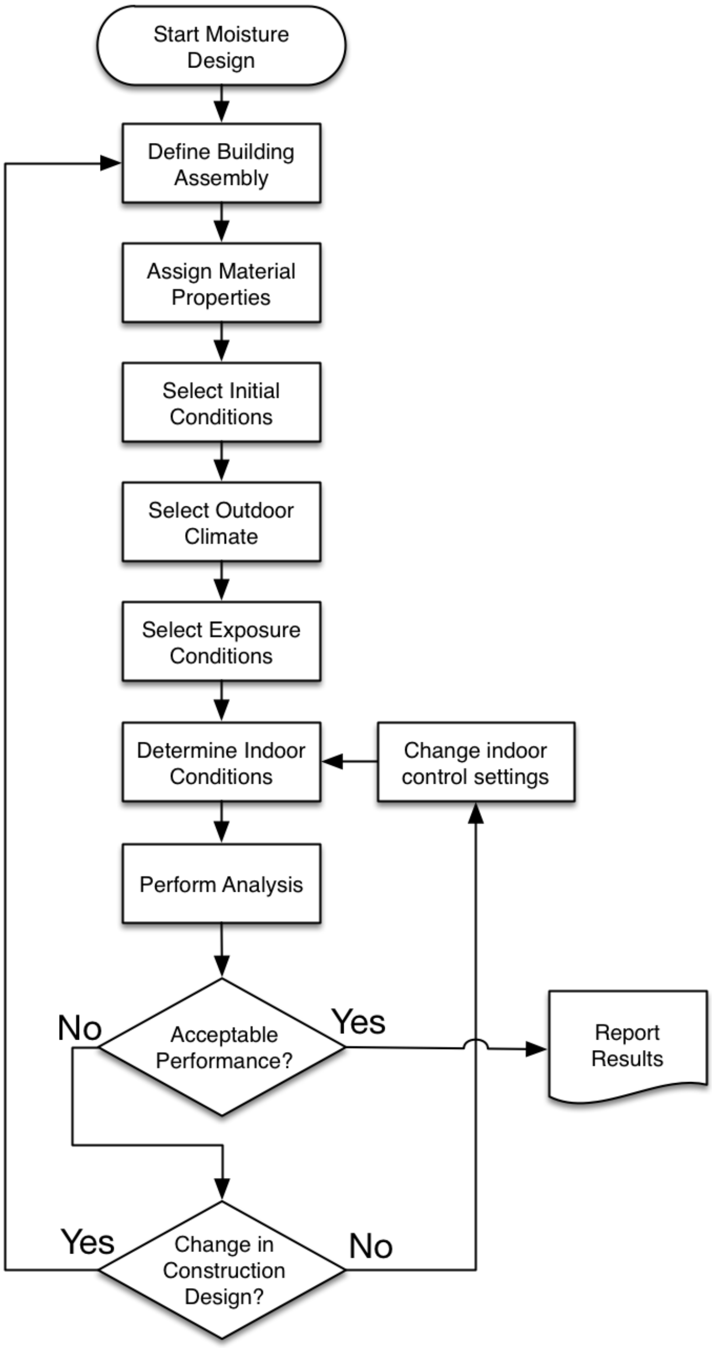


Figure 5 Flowchart or general moisture-design analysis (adapted from ASHRAE 160-2009)

5.1.2 Possible WUFI pitfalls

Material data

A comprehensive set of data is required for most types of material to perform a rigorous analysis. WUFI has a built-in material database, but there are only a few New Zealand-specific materials in the database at this stage. There are generic substitutes in the WUFI database, although these should be used with caution since the incorrect choice of material can lead to some wrong assumptions.

Climate data

As discussed earlier, outdoor climate data is provided with WUFI from a set of energy test reference years. However, there is no indoor data provided. This is where users can inadvertently cause major issues by arbitrarily specifying indoor conditions. Care should be taken that the chosen indoor conditions do not lead to unrealistic vapour pressure differences between indoors and outdoors. This can happen by increasing the indoor temperature, without considering the effect on relative humidity, which should generally be reduced in these situations.

Numerical issues

WUFI solves a system of differential equations, and numerical errors can cause issues. The solver in WUFI is quite robust, but the user should still be wary and keep an eye out for possible problems.

Surface transfer coefficients

Surface transfer coefficients, both thermal and moisture as well as solar absorption/emission coefficients, will have a significant effect on the results of a WUFI simulation. They are the link between the model and the boundary conditions/climate and form a critical part of the equation. Knowledge of any paint films/coatings is an advantage here.

Ventilation

Since ventilation can dominate the overall transport of moisture, it is desirable to include this effect in any simulation. WUFI has the capability to account for ventilation processes, but thought should be given to how representative they are. It can be difficult to effectively model cases where the ventilation air comes from multiple sources, which is likely to be the case in roof spaces. This is one reason why a nodal model is being developed at BRANZ (see below).

Sanity check

As with any type of computer modelling, the output is only as good as the underlying assumptions. At the conclusion of a modelling run, take a step back and consider the output from several angles, looking carefully for anything that contradicts your experience and questioning it. In particular, look at cladding temperatures, direction of energy flows and whether there are unusual moisture content trends.

5.2 Current research at BRANZ on analysis of roofs

5.2.1 Nodal models

In order to overcome some shortcomings of other heat moisture modelling tools, BRANZ is developing a nodal model that is able to calculate the heat air moisture (HAM) balance in building structures. An advantage of this method is that the nodal model can run simulations that take the dynamic ventilation and wind-driven infiltration rate in building cavities into account. This allows a more complete picture of the HAM dynamics of a roof or other building structure that involves air cavities.

At this stage, the nodal models developed at BRANZ are intended to calculate the impact of ventilation on moisture content of building structures such as roofs and living spaces. Initial results from the nodal model will be available in 2015, but it is planned to continue to benchmark the model against real roofs.

The idea behind a nodal model is to represent key components of the building structure as nodes that hold material properties and connect the nodes via transport resistances. The full roof geometry can't be accounted for in a nodal model, but the model can solve the overall performance of a roof quite quickly. Critical performance parameters can then be identified by varying properties and resistances in the nodal model. Figure 6 is a graphical representation of a nodal model that represents a steel-clad roof with air cavity, ceiling insulation and timber (pine)-based moisture storage.

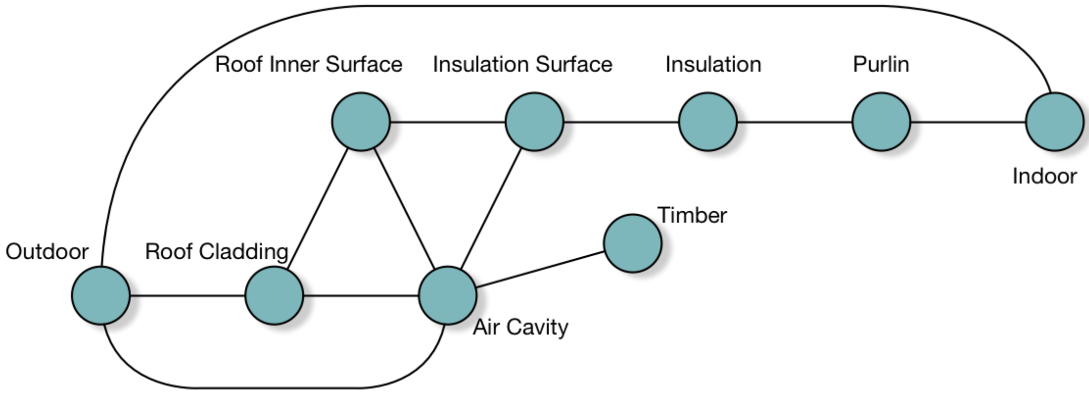


Figure 6 Nodal model of a steel-clad roof

5.2.2 Detailed-geometry roof models

The nodal model described above is the short to medium-term platform that BRANZ will use for simulating the effects of roof ventilation. In the future, it is likely that computer fluid dynamics (CFD) simulations will allow an even more detailed representation of temperature, moisture concentration and air velocity than the other modelling tools. The challenges relating to CFD are that this type of analysis requires a knowledge of the detailed boundary conditions and is very costly in terms of computation time. Expert knowledge is needed to build and run these models to obtain reliable results because there are often issues relating to convergence.

A new BRANZ project – Detailed Roof Geometry Simulation – is intended to build detailed roof models to simulate the full HAM dynamics of roofs in different climate zones, under different moisture loads and geometries. Such models are so computer-intense that they can only be solved in a sensible time using a high-performance computer cluster. Figure 7 shows a 2D slice through a commercial steel frame roof model that is currently under development. The colours relate to the magnitude of the air velocity. The driving force for the air motion in this example is the wind velocity impacting on the left-hand fascia.

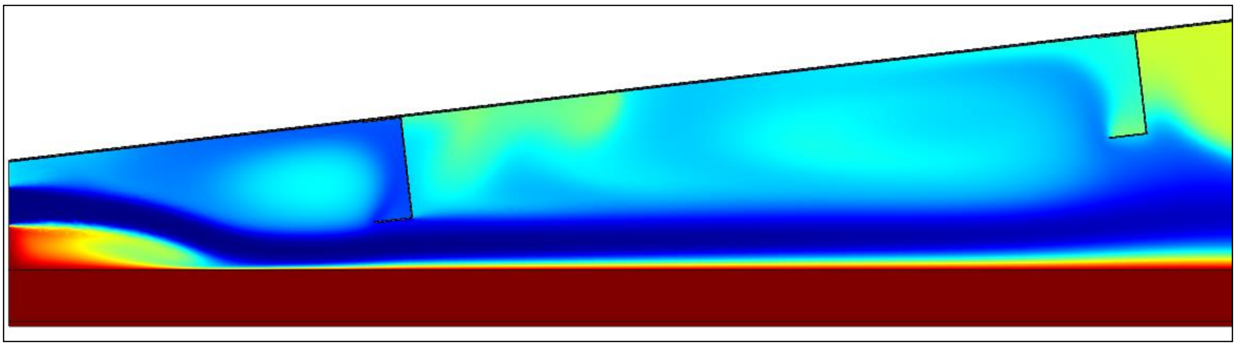


Figure 7 Example of a CFD model of a commercial-style roof space

6. A PATHWAY TOWARDS A DESIGN FOR ROOF MOISTURE MANAGEMENT

The document has summarised overseas roof moisture design processes along with the results of relevant New Zealand research. There are still several important variables that are not adequately known here. Figure 8 illustrates a process as a starting point for discussion.

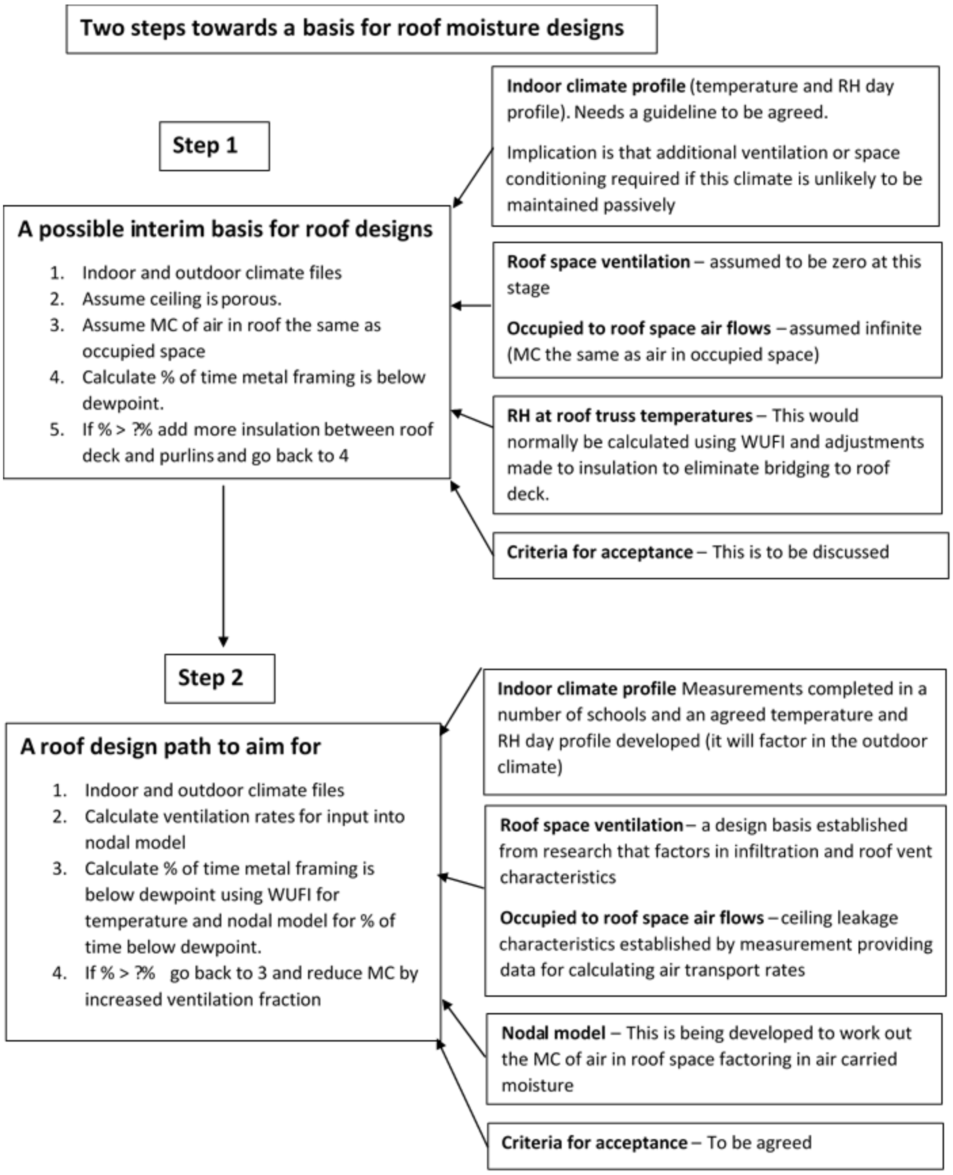


Figure 8 A conservative approach to roof design for schools – step 1 essentially describes a warm roof, while step 2 can be a cold roof cavity with given ventilation parameters

Step 1 outlines a set of assumptions that lead to a conservative design – essentially a warm roof with insulation to prevent corrosion taking place. It does not control any of the airflows because they are not well understood (particularly infiltration) in modern and large school roofs. It requires agreement on a design indoor climate (which should relate to the outdoor conditions in some way) and the atmospheric conditions that support corrosion. Step 2 allows for roof ventilation and air permeability of the ceiling lining to be factored into calculations, allowing some options for managing roof space moisture to be capitalised on.

7. RECOMMENDATIONS

This document reviewed information related to roof designs for moisture control and found that more data and defined methods are needed to support this process in New Zealand.

The following recommendations are proposed:

1. Formation of a small working group of designers, building owners and building researchers/scientists to agree on an interim set of guidelines (see Step 1 in Figure 8).
2. Establishment of a prioritised list of data by the working group. This will include indoor climate data measurements, airtightness of existing structures (roof elements and ceiling) and work on finishing the roof heat and moisture zone model.
3. Collection of field measurements of indoor climate and adaptation of the ASHRAE method of calculating a design climate from occupancy and outdoor climate data.
4. Completion of field studies of infiltration in large roofs and building a calculation basis for this.
5. Completion and validation of the nodal model.
6. Compilation of all information gathered to create a standardised process to benefit the industry.

8. REFERENCES

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