DESIGNING FOR RESILIENCE: iDEAL HOUSE AUCKLAND

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ABSTRACT

The iDEAL house is a private family home, located in suburban Auckland and due for completion in July 2014. The design brief by the client, asked for a highly energy efficient and net zero energy home within a modest budget, whilst maintaining a high level of indoor environmental quality. Outstanding thermal performance of the building envelope was essential to achieving the aspirations of this brief. In order to safeguard the performance targets, the project underwent Passive House Certification (pending).

A far more detailed analysis was undertaken than would normally occur for a family home. Interstitial condensation, mould and structural decay issues were particular concerns that were evaluated and addressed. This paper will discuss the results of this analysis, and the hygrothermal performance of the building envelope that can subsequently be expected.

Results were obtained using the following analytic tools:

- Passive House Planning Package (PHPP)[1], for Passive House Certification, to ensure compliance with the Passive House performance targets;
- Wärme und Feuchte Instationär (WUFI®)[3] for calculation of the transient coupled heat and moisture transport in multi-layer building components exposed to natural indoor and outdoor environment.
- Psi-Therm[4] for the calculation of thermal bridging coefficients to limit the additional heat loss, as well as assessing resulting interior surface temperatures, to prevent discomfort and surface condensation throughout the building.
- On site Blower Door testing for airtightness of the building envelope.

Measures and construction details that were identified to meet the performance targets are presented, also with regard to their fit with the requirements of the New Zealand Building Code Clauses[5-8] and the budget constraints of the project. This paper will demonstrate that an aspirational brief can be answered with limited additional cost when proper design strategies are employed.

KEYWORDS:

Managing moisture; thermal, isothermal and hygrothermal analysis; airtightness; resilience; blower door testing.

INTRODUCTION

The iDEAL home is intended to provide a working example of how a resilient home could be constructed in suburban Auckland using common building materials. An important feature of the home was to not only be highly efficient but also be aesthetically appealing to the modern urban family. It was essential to understand that there was to not only be a dramatic improvement in energy efficiency and thermal performance, but this was not to come at the expense of modern comforts or compromise the indoor air quality and health of the occupants.

To ensure the home meets these aspirations, it has been designed with the goal of becoming a Certified Passive House (pending). At such high levels of energy efficiency, energy demands can be met with a modest solar PV array allowing the home to operate with net zero energy.

In this paper we will detail the analysis process that was undertaken during the design phase to ensure that actual thermal energy demands match those that were predicted for the design.

Figure 1. Rendering of the iDEAL House, supplied by S3 Architects Ltd

The home is a rectangular shape with a second storey mezzanine for part of the plan area. The adjoining garage is outside of the thermal envelope and has been positioned such that it provides an interesting form to the building without compromising the thermal or airtightness performance.

The form of the house was the first key factor in ensuring good performance. A simple two storey rectangular form has a limited surface area for heat losses and containing a reasonable volume for the internal spaces. Having a surface area to volume ratio less than 1:1 ensures an optimised design. Reducing the surface area also ensures a more cost efficient construction; there is less cladding area material and other associated material volumes such as insulation, linings, paint, etc. A larger surface area would also have required a proportional increase in the levels of insulation required for the building to make up for the increased heat losses; heat loss being directly proportional to surface area.

PASSIVE HOUSE CERTIFICATION

A Passive House is well planned during the detailed design phase, however, the certification of a building is undertaken at the completion of construction. The process involves a combination of on site quality assurance checks together with a review of the as-built design details, product data sheets, analysis reports and calculations. These are compiled by the Passive House Designer and are submitted to an independent Passive House Certifier for verification.

The core performance criteria for a Certified Passive House: -

- Meeting an envelope airtightness level less than 0.60 air changes per hour (ACH) at 50 Pascals pressure differential. This is tested on site at the project completion through a Blower Door test under both pressurisation and depressurisation in accordance with Method A of EN 13829[12].
- The specific heat demand is to be less than 15kWh/(m^2) per annum. The New Zealand Building Code[8] has no specified performance benchmark for New Zealand homes, however from experience, we believe that the average modern code minimum home in Auckland would have a specific heat demand in the order of 40 to 50kWh/(m^2) per annum. Thus, a Certified Passive House would have a performance improvement of around 60 to 70% to the average code minimum home in the region.
- The cooling demand, including dehumidification shall be less than 15kWh/(m^2) per annum + 0.3 W/(m^{2}K) per annum x Dry Degree Hours.
- The heat load and cooling load must be less than 10W/m^2.
- The primary energy demand must be less than 120 kWh/(m^2) per annum.

- Using a balanced heat recovery ventilation system, with a least 75% efficiency through the heat exchanger. A large number of heat recovery ventilation systems have been independently tested by the Passivhaus Institut and are Certified Components. Using Certified Components means that no additional documentation needs to be supplied to verify compliance and the performance of the system is guaranteed.
- Having an essentially thermal bridge free construction so that the specific heat energy demand criterion is achievable and to keep internal surface temperatures well above dew point temperature. This is essential to ensure there is no interstitial condensation and mould free construction.
- Ensure the building envelope is not at risk of interstitial condensation.

The bulk of these calculations are completed in a spread sheet developed by the Passive House Institute called the Passive House Planning Package (PHPP)[1].

Thermal bridging calculations are prepared using isothermal analysis software called Psi-Therm[4] that enables the calculation of the thermal bridging coefficient or Ψ-factor. These are subsequently input into the PHPP[1]. Checks on the building envelope details for the transfer of water vapour and condensation risk are conducted through hygrothermal analysis using WUFI® Pro 5.0[3].

THERMAL MODELLING

Passive House Planning Package (PHPP)[1]

PHPP uses an energy balance method as the basis of verifying that the Passive House Standard has been met. PHPP is regarded as being highly accurate, up to +/- 0.5kWh is claimed, and has been repeatedly verified, through validation, using dynamic simulations as well as testing of actual realised buildings through meticulous measurements over several years.

The tool is based on physical principals using European norms, calculating heating, cooling and primary energy demand, as well as determining summer overheating periods. We have also undertaken independent verification using Integrated Environmental Solutions <Virtual Environment> (IES <VE>)[2] thermal analysis of the building envelope to establish specific heat energy demand.

The climate data set for the Auckland region is now pre-loaded in the latest version of PHPP8.5. This data set originated from IWEC (International Weather for Energy Calculations from ASHRAE) and was compared with NIWA data. The Passivhaus Institut independently tested the data set to ensure validity.

Opaque components

The U-Value calculations for the opaque building elements are based on International Standard ISO 6946[9]. There are a number of notable differences with this standard compared with NZS4218:2009[11] that are worth discussing: -

- ISO 6946 uses a slightly different set of interior and exterior surface resistances, offering more alternatives of heat flow scenarios that are ore realistic for heat loss calculation.
- Any cladding to the outside of a ventilated cavity is excluded from the U-Value calculation. Unlike NZS4218, which uses a method of de-rating those layers, ISO 6946 allows still areas to be considered, however a vented cavity should not be considered still air.

The final U-Values calculated for the iDEAL house are tabulated in Table 1 based on ISO 6946.

Table 1 – Opaque building component U-Values from PHPP compared with minimum NZBC[8] R-Values

Element	U-Value, W/(m^2K)	Total R-Value, (m^2K)/W	H1 minimum code R-Value, (m^2K)/W
Ground floor	0.433	2.31	1.3
Exterior walls	0.282	3.54	1.9
Southern exterior wall	0.209	4.78	1.9
Roof	0.183	5.46	2.9
Mezzanine overhang	0.208	4.81	1.3

The areas of each of the building assemblies are tabulated in the PHPP, and the respective heat losses are calculated. We have made a comparison using NZBC H1 minimum code requirements in Table 2 and we can see there is a 53% reduction in heat loss of the opaque building components compared with a code minimum home.

Table 2 – Opaque building component heat losses compared with minimum NZBC levels

Element	Area, m^2	Element Heat loss W/K	H1 minimum code heat loss, W/K
Ground floor	163.3	70.7	125.6
Exterior walls (net)	216.32	61.0	113.9
Southern exterior wall (net)	29.51	6.2	15.5
Roof	186	34.0	64.1
Mezzanine overhang	6.25	1.3	4.8
Total		173.2	323.9

The PHPP element areas are measured using exterior dimensions using the convention given in ISO 13789[16]. This yields a more conservative result as there is a degree of double measurement at the junctions and corners. Junctions have slightly larger heat losses due to geometrical thermal bridging.

To adjust for the thermal bridging that occurs at the junction of elements a thermal bridging coefficient (Ψ) is calculated using Psi-Therm, in accordance with ISO 10211[10], and is entered into the PHPP together with the respective lengths of the thermal bridges. As there was some conservatism in the measuring of the overall element areas, taking the thermal bridging effects into account will often reduce the total heat loss, so long as the proposed junction detail is sensible.
For example, the external roof barge was calculated to have Ψ = -0.199 W/(mK) with a length of 61.2m, this results in a heat loss reduction of -12.2 W/K. Examples of this calculation are discussed in more detail further in this paper.

Heat losses through the ground follow the EN ISO 13370[13] standard, taking building geometry into account. The larger the floor slab, the lower the heat losses, due to the insulating effect of the soil. Seasonal ground storage effects are also included in the calculation as it separates heat flow into steady state and harmonic components.

Windows

The windows selected for the iDEAL house are a Passive House Certified Component. This means the windows can be easily selected from the list of components and performance data is pre-filled in the tables. Aluplast PVC windows with ClimaGuard triple glazing were selected for the project. This has glass U-Value = 0.69 W/(m^2K), frame U-Value = 0.81 W/(m^2K), and edge spacer Ψ = 0.027 W/(mK). The total window area is 85m^2 with a ratio of glazed area of 56m^2 and frame area of 29m^2.

The breakdown of heat losses through the window components as determined through PHPP is given in Table 3.

Table 3 – Window component heat losses

	Glass, W/K	Frame, W/K	Spacer, W/K	Installation, W/K
South	1.10	0.97	0.29	0.43
East	9.99	7.00	2.05	2.57
North	10.9	6.03	2.68	1.90
West	16.6	9.26	1.76	2.60
Total	38.6	23.3	6.78	7.5

Total window heat loss = 76.18 W/K, and the total average window U-Value = 0.90 W/(m^2K) or R-Value = 1.11 (m^2K)/W, using ISO 10077.1.

When comparing with minimum H1 requirements from the New Zealand Building Code, we only need a window R-Value of 0.26 (m^2K)/W giving a heat loss of 325 W/K. Passive House windows for this example offers approximately 77% reduction in heat losses compared with a standard aluminium window with double glazing. The windows are where a Passive House makes significant performance improvements.

We note that NZ4218 takes a highly simplified approach to window losses, where many variants are not taken into account. This subsequently leads to a higher level of inaccuracy, which is problematic when analysing energy efficient buildings. The effect of the spacers and installation thermal bridges can be significant.

Consider if standard aluminium edge spacers were used in the iDEAL house windows, the heat losses for this element would increase from 6.78 W/K to 27.9 W/K. This is greater than the heat losses through the PVC window frames. This indicates that to obtain a return on investment on any thermally broken frame, a high performance glass edge spacer is essential.

Certified Passive House windows consider more than just the thermal and airtightness properties. The hygiene requirement restricts the minimum interior surface temperature on the window. This is to ensure that condensation cannot consistently form on the window that subsequently leads to mould growth. The relative humidity in either the window materials pores or directly on its surface cannot exceed 80%. This ensures a healthy living environment.

The other requirement is for comfort. This restricts the average indoor temperature to the minimum surface temperature of the window by a maximum of 4.2K. With a 20^{o}C indoor operative temperature environment, the window surface temperature must effectively not fall below 15.8^{o}C. This ensures there is no downdraft effects and no perceptible radiant heat deprivation, thus there is a comfortable living environment.

The New Zealand Building Code Clause E2/AS1[6] has a prescriptive approach to the installation of windows as a measure to prevent water ingress from wind driven rain. Ironically, the windows have large thermal bridges that cause condensation on the interior face of the window components during winter months. In many cases, if the thermal bridging was addressed and the window was installed in an airtight manner, the moisture issues could be eliminated.

Having to install the windows to E2/AS1 requirements meant that the installation thermal bridging effect was exacerbated. We used a higher performance frame than would normally be required to overcome this performance limitation. There was a reluctance to detail an Alternative Solution, as the design team felt this would raise uncertainty during the Building Consent phase of the project.

The PHPP assumes a very conservative installation thermal bridging coefficient of $\Psi = 0.04$ W/(mK) as default, with the worst case always occurring at the window or door sills.

Uncertified windows would require calculation of the frame U-Value to be determined based on ISO 10077[14], similar applies to the glazing U-Value, together with the edge spacers and installation thermal bridging co-efficient. Analysis to check the hygiene and comfort requirements should also be undertaken. We initially worked through such calculations using thermally broken aluminium window suites for the iDEAL house. However, the restrictive nature of how the window had to be installed to meet E2/AS1 meant that we could not meet the hygiene or comfort criteria necessary for Passive House Certification. We therefore moved to using an imported PVC window frame that was Passive House Certified.

New Zealand aluminium window manufacturers are only just starting to adopt ISO 10077 for the calculation of the window component U-Values. This will allow a more consistent approach and allow performance to be properly compared with overseas products. So far, the fabrication and installation of locally manufactured aluminium framed windows has not been consistent enough for us to be confident that they could always meet the airtightness requirements for a Certified Passive House.

To ensure solar gains are accurately calculated in the energy balance, shading effects are taken into account. This includes eaves, screening devices and overshadowing structures and topography.

Heat Recovery Ventilation

Although not directly related to our analysis, it is worth mentioning the balanced heat recovery ventilation system as it is often queried. A balanced heat recovery ventilation system is an important asset for a Certified Passive House. It enables fresh air to be brought into the home in an energy efficient manner. During mild weather, opening windows can be satisfactory for providing the fresh

air requirement. However in colder months this would introduce cold air indoors, which would require heating energy to bring it back up to the ideal operative temperature of 20°C.
There are other practical benefits of having a balanced heat recovery ventilation system: -

- All of the incoming air is filtered and aggravating allergens and pollutants can be scrubbed.
- There is greater security than having to leave windows open at night or when the house is left unoccupied.
- It is much quieter when in urban environments; it quells airborne street noise coming in through open windows.
- It ensures that there is always ample fresh air throughout the house and pollutants such as VOCs don't accumulate.

A Certified Passive House ventilation system is very quiet as it can run on low air speed through the benefit of having an airtight construction. They operate with very minimal cost and can often return enough heat energy to the home as to avoid needing any additional space heating.

ISOTHERMAL ANALYSIS - Psi-Therm

The principal of 'thermal bridge free construction' is elemental to having a successful low energy building or Certified Passive House. We mentioned previously that areas are measured to the exterior dimension to be conservative, thus the losses occurring from geometrical thermal bridges are already accounted for in the PHPP. The heat loss coefficients for overlapping geometries normally work out to be negative when assuming exterior dimensions. Therefore, the heat losses are overestimated using this simplified method in the PHPP.

Calculating the linear thermal transmittance coefficients, or Ψ-value, can allow the heat loss to be determined with more precision. For a Certified Passive House, Ψ-values greater than 0.01 W/(mK) must be taken into account. The designer can decide whether to incorporate values less than 0.01 W/(mK) for improved accuracy.

We show the example of the roof junction with the exterior wall for the iDEAL house in Figure 2. Here a geometrical thermal bridge is occurring, but to ensure good performance with low risk of interstitial condensation there is an uninterrupted layer of insulation. To further insure there is no thermal bridging of concern, the detail is modelled using isothermal analysis.

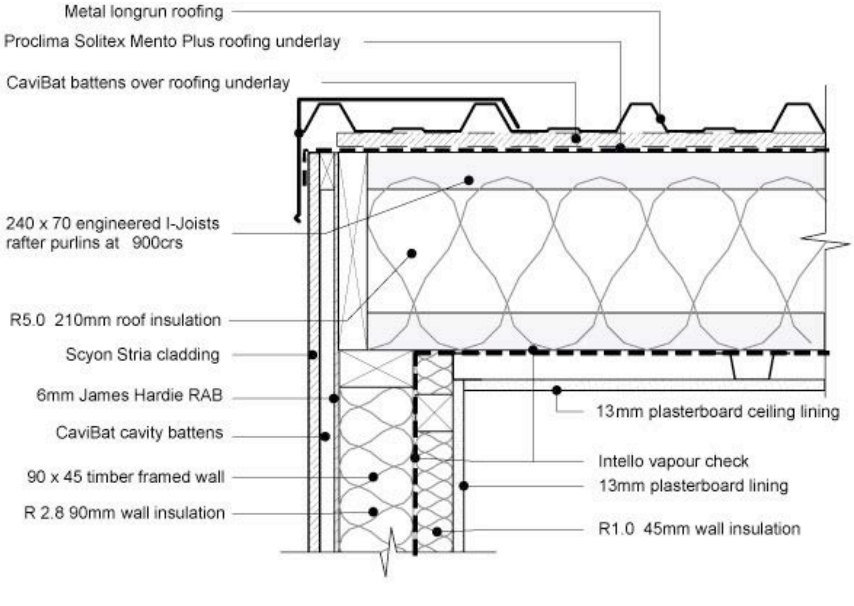

Figure 2. Roof junction to exterior wall barge detail, supplied by S3 Architects Ltd

The first stage of the analysis determines the interior surface temperatures. We used the software package Psi-Therm[4], which also post processes the data to calculate the Ψ-factor to avoid us having to manually calculate using ISO 10211[10] based on the surface temperatures. Setting the indoor and outdoor boundary conditions correctly is important to ensure the surface temperatures are matching the appropriate thermal bridging criterion.

As the dwelling is to be a Certified Passive House, we can be confident that the indoor temperature will be 20°C. The exterior temperature settings are based on the Passivhaus Institut's regional classification[17]; being warm-temperate for the north island of New Zealand. The exterior temperature boundary condition for the hygiene criterion is $\theta a = -5^{o}C$. From the analysis we determined the lowest surface temperature at the corner of the detail to be 17.04°C. This equates to $\Psi = -0.045$ W/(mK).

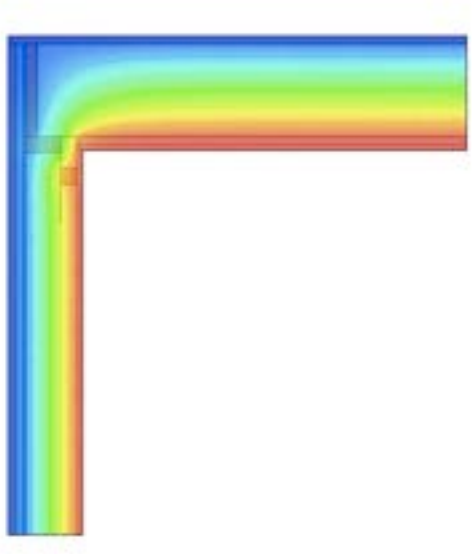

Figure 3. Roof junction to exterior wall isothermal modelling results using Psi-Therm software

The lineal length of the thermal bridge is 61.2m, effectively reducing the overall heat loss by 2.75 W/K, reducing the overall heat loss from 173.2 to 170.5 W/K. This is modest, but once all the other thermal bridges are taken into account we can typically reduce the heat loss by around 5%, meaning a borderline design can manage to meet the Certified Passive House Criteria.

HYGROTHERMAL MODELLING - Wärme und Feuchte Instationär (WUFI®)

Hygrothermal modelling has shown to be an essential part of verifying the suitability of the construction elements for the iDEAL house. The Fraunhofer IBP simulation software[3] is use to predict one-dimensional heat and moisture transfer in multi-layer building components exposed to variable climate conditions to both the indoor and outdoor surface.

With super insulated elements the risk of interstitial condensation can be heightened, particularly during winter months. This is one reason why the Passive House Institute requires such a high standard of airtightness, which controls the ingress of moisture-laden air through convection into the construction element.

Simple building physics predicts the point of the theoretical dew point in a construction; theory has it that if water vapour is generally prevented to flow into the construction, the resulting condensation cannot form. A common international method a creating a sealed environment is through the use of polyethylene vapour barriers to the interior face of the framing. Failures of these systems are becoming well documented in Europe and North America[18, 19].

When simulated in WUFI®, it becomes apparent why such a construction element would fail. Moisture becomes trapped behind the vapour barrier allowing the moisture content in the materials to rise, condensation and mould then occur. If the vapour barrier is not fully sealed and airtight, the leakage points exacerbate problems. The energy driver moving from warm to cold can also be reversed in summer months, allowing water vapour to be carried into the construction from the exterior. Very few building wraps can resist this infiltration and they would need to be installed with greater care with all the gaps fully sealed.

In practicality, these techniques are hard to implement, the materials can be hard to work with, construction workers don't always understand the impact of their work and the competition in the housing market means that quality standards can easily slip. Climate differences also mean that some details are not suitable universally.

There are two main construction details we analysed for the iDEAL house, the skillion roof and the exterior wall section. The construction details for these elements were illustrated in Figure 2. The insulation material used in the construction was Knauf Earthwool® fibreglass. The roof construction has proven to be the more critical case and is examined here in more detail.

The roof construction utilises a ventilated cavity design approach between the metal roofing and the roofing underlay. This ensures that there was complete back diffusion capability in the construction and that moisture can move out when necessary. The interior face is lined with Pro Clima INTELLO® for airtightness and prevention of water vapour transport into the construction under an outward energy flow. Moisture can however move out of the construction on the interior face as the INTELLO® vapour check can remain open to diffusion under these conditions.

To explain we prepared four different cases, the as-built construction, removing the vapour check, replacing INTELLO® with a vapour barrier and adding an additional layer of plywood sarking on top of the rafters.

The two critical zones in the construction are the two outer extremes of the fibreglass insulation layer. To ensure the results at these points are not averaged over the full depth of the layer, we model a 10mm slice of fibreglass at each face. The WUFI® analysis results are run through a post processor called WUFIBio, which is a tool that assesses the risk of mould growth[20, 21]. Results are presented in Figures 4 and 5.

The first output graph shown in Figure 4, shows the mould growth over time through the inside slice of fibreglass insulation. The performance is considerably worse when a vapour barrier is used compared with a layer of INTELLO®, or even no vapour check. The program indicates an amber light as a warning that mould growth risk is high for the vapour barrier case and the graph clearly indicates that mould is building up over time whenever the water content is raised over the critical moisture content. This is generally in line with industry advice in New Zealand.

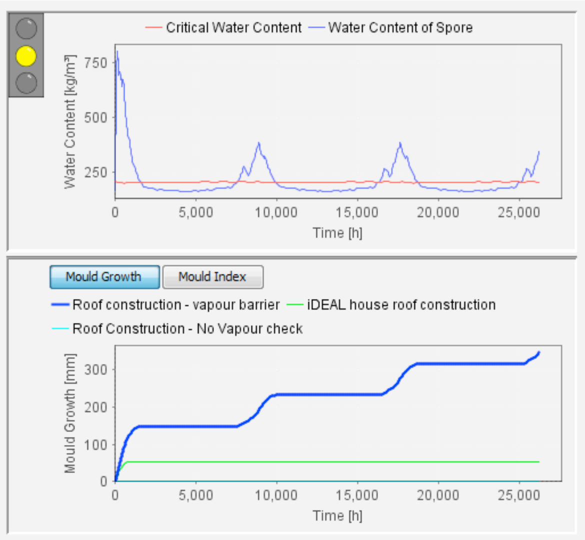

Figure 4. WUFIBio graph results for inner face of fibreglass layer

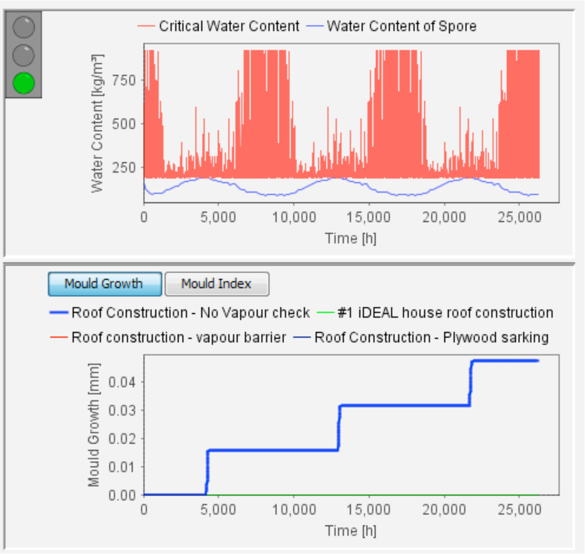

Figure 5. WUFIBio graph results for outer face of fibreglass layer

What is interesting is how the vapour check effects moisture on the outer surface of the insulation layer. If there is no vapour control layer, there is again a continual increase in mould activity over time as the moisture content is very close to the critical water content, as seen in Figure 5. If there are any exacerbating situations such as extended cold and wet periods, or if the interior relative humidity is allowed to become elevated for periods of time, mould problems will become evident. If we were in a slightly colder climate, this behaviour would become far worse. Changing the climate zone from Auckland to Queenstown increased mould growth from less than 1mm over three years to a theoretical 750mm depth. The structural decay would overwhelm the building within early life as indicated by Figure 6.

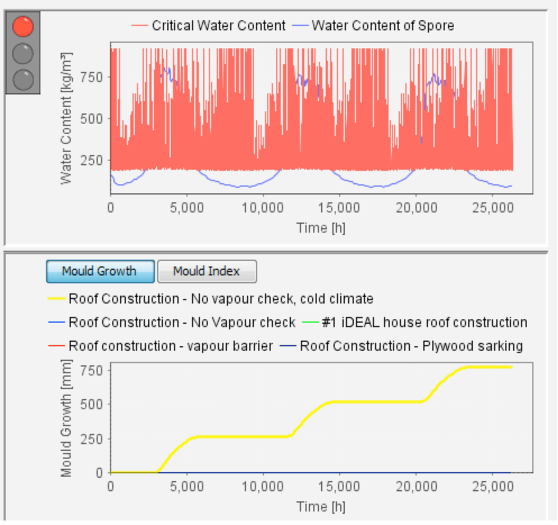

Figure 6. WUFIBio graph results for outer face of fibreglass layer, Queenstown climate

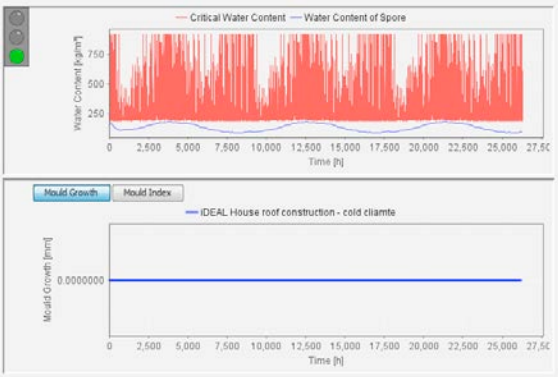

Figure 7. WUFIBio graph results for outer face of fibreglass layer, Queenstown climate, with INTELLO®

Using a vapour check such as INTELLO® completely eliminates the mould risk for this same detail with the Queenstown climate applied as can be seen in Figure 7. Queenstown is regularly seen as a dry environment.

Thus we can conclude that a vapour barrier is not advisable, as this could lead to a risk of mould to the interior surface of the insulation. Conversely, if there is no vapour control layer at all, the outer layer of the insulation can become at risk of mould. The best balance between these two opposing physical behaviours is to use a humidity-variable vapour check such as INTELLO®.

BLOWER DOOR TESTING - AIRTIGHTNESS

High levels of airtightness for the building envelope are a core feature of a Certified Passive House. This has been controversial and often misunderstood. An airtight building does not mean it is sealed, there are still opening windows that the occupants are free to use as in any normal building.

The airtightness envelope prevents unintended air infiltration through the building construction elements. This is a form of heat loss from the building and can be considerable if left unchecked. When working with high-energy efficient buildings there are usually more efficiency gains to be made through eliminating infiltration than there is by simply adding more insulation.

As was evident from our previous discussion of the hygrothermal analysis, an airtightness layer can be used as a vapour check and is essential to avoid unwanted moisture vapour entering into a building component. Effective airtightness eliminates much of the dust and pollutants entering the indoor environment. It makes ventilation and convective heating systems work far more effectively.

Airtightness is readily measured on site through a Blower Door test, which can pressurise or depressurise the building. Performance measures are in terms of volume air changes per hour (ACH) with a 50 Pascal pressure differential (n_{50}). A Certified Passive House must have an airtightness measure less than 0.6 ACH. Final verification is conducted when the building is completed, so that the measure is effectively an in-use value. This is known as a Method A Test in accordance with EN 13829[12].

As the iDEAL house is not quite complete at the time of preparing this paper, the final air tightness verification has not been completed.

CONCLUSION

Having an accurate model of a building allows tuning of the building component design, which is especially important when investing in a high energy efficient or net zero building. Overinvestment in some building components may not be realised, whereas underinvestment in essential elements could lead to serious early demise of the building. The analysis procedures provide a methodology to determine these priorities.

The detailed analysis completed for the iDEAL house allowed us to verify, during the design phase, that there were no long term performance issues in the home. We can be confident that the design does not have excessive thermal bridging, which not only leads to inefficiency through heat losses, but can also put the structure at risk through surface condensation. We also established that the construction elements were free from risk of structural decay and that a vapour check was a necessary investment for long term structural durability.

For a resilient home, the long term thermal performance and comfort needs must be met to ensure security for a low energy future. A resilient home must also be durable and resistant to structural decay so that it can endure and realise the investment that has been made.

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