Tools to assess internal surface mould growth: dynamic vs static

Griffin Cherrill¹, Michael Donn², Nigel Isaacs³ and Stephen McNeil⁴

¹, ², ³School of Architecture, Victoria University of Wellington, Wellington, New Zealand
{griffin.cherrill¹, michael.donn², nigel.isaacs³}@vuw.ac.nz, 0000-0001-6890-6843¹, 0000-0002-4716-4286², 0000-0002-1348-4644³
⁴Building Research Association of New Zealand (BRANZ), Judgeford, New Zealand
steve.mcneil⁴@branz.co.nz

Abstract: The paper reports on research to identify a reliable tool to take account of thermal bridging. This will allow designers to evaluate the performance of timber-framed construction and the potential for internal surface mould growth. The Isothermal Planes method required by New Zealand Building Code Clause E3/AS1 to avoid internal moisture is too simplistic, therefore a more reliable tool is required. This paper compares the results from the static (moment in time) tool THERM and the dynamic tool WUFI 2D. Internal conditions were estimated by following Appendix A.1 of ISO 13788:2012 and calculated using a calibrated whole building simulation, WUFI Plus. The Temperature Factor and VTT Mould Growth Index were used to interpret the results from the static and dynamic tools, respectively. When ISO 13788:2012 is used to estimate the internal conditions, the risk of mould growth concluded from the static and dynamic tools is inconsistent with the measured data. The reason is that ISO 13788:2012 assumes internal relative humidity (RH) does not exceed 70% RH, yet mould growth commences at 80%. When internal conditions from the calibrated whole building simulation were used in WUFI 2D, the risk of mould growth was consistent with the measured data. Although using a dynamic tool over a static tool is preferred to simulate over time and account for the changing external climate, the results also highlight the importance of applying correct internal conditions, especially when assessing risk.

Keywords: Simulation; mould; static; dynamic.

1. Introduction

The method in Clause E3/AS1 of the New Zealand Building Code (NZBC) used to avoid internal surface moisture in habitable spaces requires the overall R-value of a timber-frame wall to exceed R-1.5. This method ignores the impact of multiple timber studs (thermal bridges) that cause cooler surface temperatures, which potentially lead to an increased risk of condensation and mould growth. Clause E3/AS1 states “fungal growth (mildew) is avoided by minimising internal condensation”, when in reality, mould can grow with a surface relative humidity (RH) of 80% but condensation forms at a surface RH of
100% (Standards New Zealand, 2017). This method may still permit local internal surface temperatures to drop below the critical temperature and encourage mould growth and condensation. It has already been identified as inadequate (Cherrill & Donn, 2020); therefore, this research aims to identify a more reliable tool that can be used to calculate surface conditions and assess the risk of mould growth and condensation in the New Zealand situation.

A range of simulation tools are available that can be used to calculate the conditions inside a building and on the surface. Simulation tools allow a designer to assess the performance of their building considering the material properties of constructions used, as well as accounting for other activities, such as ventilation, space conditioning and internal loads. But the tools available are not all equal, especially when used to calculate the internal surface conditions rather than the energy demand. A literature review, reported in Cherrill and Donn (2020), found there are various factors that dictate the abilities of a tool and the reliability of the results it produces.

In a broad sense, there are two types of simulation tools which can be used to understand the surface conditions to be found in a building: Building Component Simulation (BCS) and Whole Building Simulation (WBS). WBS are usually used to estimate the energy demand of a building while a BCS gives a clear idea of the internal surface conditions of a construction in a specific area of the building. A BCS can simulate a specific part of the building, for example a junction where a wall intersects with a floor, whereas a WBS simulates on a larger scale, treating each room of the building as a thermal zone. A BCS can usually produce more reliable results of the internal surface conditions as it can model heterogeneous constructions, including thermal bridges, but a WBS can account for the wider context of the building, including external climate conditions, building geometry, internal loads, space conditioning and external shading. Where a WBS can calculate the hygrothermal conditions inside a zone, a BCS will require the user to estimate internal conditions or use measured data.

Within BCS, there are multiple factors that dictate the complexity of the tool, the time it takes to simulate a given construction detail and the reliability of results. These factors include the simulation conditions (static or dynamic), the number of dimensions the tool simulates in (1-Dimension, 2D or 3D) and the material properties used (thermal or hygrothermal).

To get a realistic idea of the conditions on the surface of a point thermal bridge, where three building surfaces intersect and the risk of condensation and mould growth is at its greatest, Cherrill and Donn (2020) argued for the use of a 3D dynamic hygrothermal tool, the most comprehensive tool. But when going along the spectrum of tools from the least detailed 1D static thermal tool to the most comprehensive 3D dynamic hygrothermal tool, the simulation time potentially increases from a few seconds to a number of weeks, and the required inputs increase significantly.

Therefore, the aim of the wider research, of which part is reported here, is to identify how far along the spectrum of tools lies a tool that produces results that are good enough to assess the risk of mould growth and condensation, while minimising the time and experience required to get results. This paper explores the initial research findings, comparing the results from the static simulation tool THERM (Lawrence Berkeley National Laboratory, 2019) and the dynamic simulation tool WUFI 2D (Fraunhofer Institute for Building Physics, 2019).

2. Static and dynamic tools

A significant difference between static and dynamic tools is the time period which they simulate. Both tools require the modeller to electronically ‘build’ the construction detail, apply correct material
properties and surface resistance values. A static tool takes user entered external and internal conditions to calculate the internal surface temperature for a single point in time. A dynamic simulation tool uses a climate file for the external conditions to calculate the internal surface temperature for period of time, usually one year. The internal conditions used in a dynamic tool are not calculated by a BCS and have to be manually entered. These can be obtained from measured data, calculated data from a WBS, or estimated using indoor climate assumptions, such as those from ISO 13788:2012 which is built into WUFI 2D.

This paper assesses results for internal surface mould growth produced by a static tool and a dynamic tool for the same thermal bridge detail. Monitored internal hygrothermal data for the 2015 year was made available by BRANZ for a research house. External conditions were obtained from New Zealand's National Climate Database CliFlo for the 2015 year (National Institute of Water and Atmospheric Research, 2007). Measured data for the building and thermal bridge detail were compared against the results from the tools. ISO 13788:2012 was used to estimate the internal conditions of the building using the measured external data. The results from the two tools will be used to assess the risk of internal surface mould growth.

Figure 1 shows the wall-to-wall linear thermal bridge (LTB) junction case-study, with timber studs built up in the corner, insulation between, plasterboard on the internal surface and fibre-cement cladding on the external surface. The details are drawn in THERM and WUFI 2D.

---

**2.1. Boundary conditions for static tool**

The standard ISO 13788:2012 outlines “simplified calculation methods” to assess the risk of mould growth on the internal surface of buildings using a static simulation tool. Appendix A.1 and Section 4.2.3 (b) of ISO 13788:2012 use the monthly mean external air temperature to estimate monthly mean internal air temperature, internal RH and ground temperature. ISO 13370:2001 can be used to estimate the monthly mean subfloor temperature with a static thermal balance equation in Appendix F.1, using the monthly mean external air temperature and estimated internal air temperature.

Section 4.4.1 of ISO 13788:2012 also provides surface resistance values to be used when calculating the risk of mould growth. It suggests the external surface resistance should be 0.04 m²·K/W, which is consistent with the values used in Table E2 of NZS 4214:2006 and Table 1 of Chapter 25 in ASHRAE.
Handbook 2001. However, it suggests the internal surface resistance should be 0.25 m$^2\cdot$K/W on opaque surfaces “to represent the effect of corners, furniture, curtains or suspended ceilings” (International Organization for Standardization, 2012, p. 6). This value is double the values found in NZS 4214:2006 and ASHRAE Handbook 2001, which range from 0.11 to 0.16 m$^2\cdot$K/W, depending on the direction of heat flow. ISO 13788:2012 gives no evidence to support the use of this value, or how it changes the risk of mould growth.

The equations used in Appendix A.1 of ISO 13788:2012 use the external air temperature to estimate the internal temperature and RH. There is an assumption that the internal air temperature is always between 20°C to 25°C and the internal RH does not exceed 70%. Although these conditions could be considered as ideal for all houses, they are unrealistic in the New Zealand setting.

The HEEP Study conducted by BRANZ in 2010 found the national mean summer daytime living room temperature was 21.8°C, which aligns with the assumption made with ISO 13788:2012. However, in the standard, the critical month, usually in winter, is used to assess the risk of mould growth. The HEEP Study found the national mean winter evening living room temperature was 17.9°C.

A later study, conducted by Plagmann et al. (2021) in 2016 and 2017, agrees with these findings from the HEEP Study. Their study found the national mean annual evening bedroom temperature was 17.3°C, with 100% of the houses recording a temperature lower than 21°C for 96% of the time in 2016 and 94% in 2017. The study also measured bedroom RH over the year of 2016 and 2017. The results show 86% of the houses had an RH greater than 70% for 23% of the time in 2016, and 83% of the houses had a RH greater than 70% for 28% of the time in 2017. In more than 4/5 of the houses, the RH exceeded 70% for around 1/4 of the year (Plagmann et al., 2021).

During the time when the RH is over 70% the risk of mould growth is at its highest, but the ISO 13788:2012 assumptions are that the RH cannot exceed 70%. For this risk assessment, the conditions should be the worst-case scenario in order to ensure adequate building performance most of the time.

2.2. Boundary conditions for dynamic tool

Unlike a static tool which gives a snapshot at one instant of time, a dynamic tool simulates over a period of time, usually every hour for one year. It requires a set of values with the external and internal air temperature and RH. The external conditions can be obtained from measured data specific to the location of the building, or a representative weather file. For this research, a custom weather file with hourly temperature, humidity, solar radiation, rain and wind data was created for the 2015 year using measured data from NIWA ClimFlo.

The internal conditions are not calculated by the dynamic BCS as it only simulates a single junction, rather than the whole building. Therefore, the internal conditions can be obtained from measured data if available or calculated using a WBS. Using the WBS tool WUFI Plus, a model of the case study house was calibrated against internal measured data for the 2015 year. The model results were within the tolerance bands for calibrating internal conditions, identified by Huerto-Cardenas et al. (2020). As the measured data was recorded when the house was unoccupied, once the model was calibrated an internal moisture load was added to represent an occupied house. Some tools, such as WUFI 2D, can use indoor climate assumptions, such as those from ISO 13788:2012, to estimate the internal conditions. Again, this climate model assumes the temperature cannot fall below 20°C and the internal RH does not exceed 70%.

In WUFI 2D, the internal surface resistance is 0.12 m$^2\cdot$K/W, which is consistent with ASHRAE Handbook 2001 and the external surface resistance is wind dependent, calculated with the weather file.
3. Metrics for mould growth risk

The VTT Mould Growth Index (VTT Index), developed by Hukka and Viitanen (1999) based on empirical data, can be used to estimate the growth of surface mould. To assess the risk of mould growth from the results of a dynamic tool, the equations from the VTT Index are used to produce a value between $M = 0$ (no mould growth), to $M = 6$ (surface 100% covered in toxic mould) (Hukka & Viitanen, 1999). The original equations were developed to estimate the growth of mould on pine, but adjustable variables have since been added to the equations to change the material and its properties (Ojanen et al., 2010). Therefore, the assessing mould growth, the sensitivity class was set to ‘Sensitive’ to represent “wall paint for indoor use”, with a mould growth decline of 0.5 and a “cleaned” surface.

The results from a static tool are not sufficient to use with the VTT Index as it calculates the change in mould growth over time, but a static tool produces a result for a single point in time. ISO 13788:2012 provides guidance to assess the risk of mould growth using the temperature factor with the results from a static tool. The temperature factor, calculated with Equation 1 from the standard, uses the external air temperature, internal air temperature and internal surface temperature to calculate what proportion of the temperature drop across the building element occurs at the internal boundary layer.

$$f_{Rsi} = \frac{\theta_{si} - \theta_{e}}{\theta_{i} - \theta_{e}}$$

(1)

Where:

- $f_{Rsi}$ = temperature factor;
- $\theta_{si}$ = internal surface temperature;
- $\theta_{e}$ = external air temperature;
- $\theta_{i}$ = internal air temperature.

The equation produces a dimensionless value within 0 to 1, where a greater value indicates a lower risk of mould growth. To assess the risk of mould growth, the temperature factor is compared against the critical temperature factor, calculated following Section 5.3 of ISO 13788:2012 using the conditions of the critical month and a critical surface RH of 80%. If the temperature factor is below the critical temperature factor, the construction detail will encourage mould growth (International Organization for Standardization, 2012).

The metrics are used to assess the risk of mould growth but the extent of the outputs differ. Both metrics will identify whether the results from the tools indicate a risk of mould growth or not, but the VTT Index provides further information to illustrate the severity of the risk.

4. Results

Two tools are used to calculate the surface temperature of a wall-to-wall LTB junction. The static tool THERM uses measured external conditions data from 2015 and internal conditions estimated with indoor climate assumptions in Appendix A.1 of ISO 13788:2012. The dynamic tool WUFI 2D was used to produce two sets of results. The first set, similar to THERM, uses internal conditions estimated with ISO 13788:2012, and will help to identify the impact on the risk of mould growth when using a dynamic tool rather than a static tool. The second set use the calculated internal conditions from a calibrated WBS model of the building in WUFI Plus. These results will help to identify the impact on the risk of mould growth when internal conditions are calculated using a WBS and measured data rather than estimated using indoor climate assumptions.
4.1. Results from static tool (THERM)

Section 4.2.2 of ISO 13788:2012 states the mean monthly external air temperature is to be used to calculate all internal conditions. To test the impact of the external air temperature on the risk of mould growth, the same process also was followed using the minimum (rather than mean) monthly external air temperature. Table 1 shows the calculated temperature factor at the wall-to-wall LTB for July (the worst month), when the mean and minimum monthly external temperatures are used to estimate internal conditions and calculate the surface temperature in THERM.

Table 53. LTB critical temperature factor and temperature factor for mean and minimum external air temperature.

<table>
<thead>
<tr>
<th></th>
<th>Critical Temperature Factor</th>
<th>Temperature Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum External</td>
<td>0.64</td>
<td>0.70</td>
</tr>
<tr>
<td>Mean External</td>
<td>0.56</td>
<td>0.70</td>
</tr>
</tbody>
</table>

Regardless of whether the mean or minimum external air temperature is used, the calculated temperature factor at the LTB is 0.70. However, the use of the minimum external air temperature results in a higher critical temperature factor, which changes the critical threshold at which the risk of mould growth becomes apparent. Regardless, the results from THERM indicate there is no risk of mould growth at the LTB as the calculated temperature factor is greater than the critical temperature factor.

The risk of mould growth is largely dictated by the surface temperature and also by the RH of the air directly in contact with the surface (Hukka & Viitanen, 1999). The temperature factor attempts to account for surface RH by calculating the critical temperature factor with 80% of the saturation pressure. THERM calculates the surface temperature and allows for the surface RH to be specified, but this does not change the calculated surface temperature.

4.1.1. Impact of external air temperature

Figure 2 illustrates the calculation of the temperature factor for the wall construction, with a minimum monthly external air temperature -1.8°C and mean of 8.8°C in July 2015. As the external air temperature is below 10°C, ISO 13788:2012 assumes the internal air temperature is 20°C.
Regardless of the external air temperature, Figure 2 shows the temperature factor is the same, as it calculates what proportion of the temperature drop across the building element occurs at the internal air boundary. Therefore, with the same wall construction and internal surface resistance, the temperature factor will be the same even if the conditions used to calculate are different. However, Table 1 shows the monthly external air temperature influences the critical temperature factor and therefore affects the threshold at which mould risk becomes apparent.

4.1.2. Impact of internal surface resistance

In addition to Equation 1 from ISO 13788:2012, which uses the surface and air temperatures, Equation 2 from Appendix B of EN ISO 10211-2:2001 can calculate the temperature factor using the thermal resistance of the construction and the surface resistance values.

\[
f_{Rsi} = \frac{R_{value} + R_{se}}{R_{si} + R_{value} + R_{se}}
\]

Where:

- \(f_{Rsi}\) = temperature factor;
- \(R_{value}\) = thermal resistance of construction;
- \(R_{se}\) = external surface resistance;
- \(R_{si}\) = internal surface resistance.

Section 4.4.1 of ISO 13788:2012 states the internal surface resistance should be 0.25 m\(^2\)-K/W when assessing risk, rather than the value used for vertical surfaces of 0.12 m\(^2\)-K/W suggested in ASHRAE Handbook 2001. Equation 2 shows the impact of a greater \(R_{si}\) value will lower the calculated temperature factor. Therefore, the higher internal surface resistance acts as a safety margin, to lower the performance of the building detail and increase the perceived risk of mould growth.
4.2. Results from dynamic tool (WUFI 2D)

Figure 3 graphs the measured surface temperature and absolute humidity against the results from the dynamic tool WUFI 2D.

Figure 112. Measured and calculated results from WUFI 2D for (a) surface temperature and (b) absolute humidity (Internal conditions: Estimated with ISO 13788:2012 & calculated with WBS).

WUFI 2D simulated two scenarios. The first used the same conditions used in THERM, with 2015 external measured conditions and internal conditions estimated using WUFI 2D, based on ISO 13788:2012. The second scenario used the same external conditions but with internal conditions calculated from a calibrated WBS. Figure 3a (left) compares the measured LTB surface temperature (blue line) with the WUFI 2D surface temperatures using estimated (orange) and calculated (grey) internal conditions. Figure 3b (right) compares the absolute humidity for the same analyses.

Figure 3 shows a clear difference between the results from WUFI 2D when the internal climate is estimated and calculated. The ISO 13788:2012 results from WUFI 2D follow the same diurnal pattern as the measured data, but the absolute values differ. Additionally, the impact of the ISO 13788:2012 assumptions on the internal air temperature and RH is evident where the absolute humidity does not exceed 15 g/m³ in Figure 3b. With the maximum internal RH set to 70%, the risk of mould growth is reduced and therefore may not be representative of the true risk.

Results from WUFI 2D more closely align to the measured data internal conditions are calculated using the WBS. This was confirmed with the Root Mean Square Error (RMSE) of the residuals, with the surface temperature RMSE of 3.5°C estimated with ISO 13788:2012 and 1.0°C calculated with WBS. The absolute humidity residuals RMSE are 5.5 g/m³ (ISO 13788:2012) and 3.2 g/m³ (WBS).

This comparison suggests the use of a dynamic BCS tends to be more realistic than the results obtained from a static tool, as the dynamic tool can account for a changing external climate. A dynamic BCS tool alone may not be adequate if internal conditions are simply estimated. The calculated surface temperature and absolute humidity align to the measured data better when the internal conditions are calculated with the WBS, but it is unknown how these differences can impact the risk of mould growth.
Figure 113. Mould growth index calculated with results from WUFI 2D (Internal conditions: Estimated with ISO 13788:2012 & calculated with WBS).

Figure 4 graphs the VTT Mould Growth Index, the potential for mould growth over the year using measured data, and the results from WUFI 2D. When the internal conditions calculated from the WBS are used in WUFI 2D, the growth of mould closely follows the measured mould growth index. However, when internal conditions are estimated with ISO 13788:2012, WUFI 2D predicts a mould index growth of $M = 0$ (mould will not grow). ISO 13788:2012 assumptions do not permit surface RH to exceed 70% but equations from the VTT Index show the critical surface RH for mould growth is 80%. Hence, mould will not grow with this limit, regardless of the reliability of the surface temperature calculations.

5. Discussion

The results from the static tool when ISO 13788:2012 is used to estimate the internal conditions indicated there is no risk of mould growth. These results do not align with the measured data which shows the conditions will lead to a mould growth index of $M = 3$ after one year. Due to the nature of the static tool, which produces a temperature factor value to represent each month of the year, it is possible a static tool can produce unreliable results, although this will be is unknown.

A sensitivity analysis found internal surface resistance and external air temperature were the main variables to affect the risk of mould growth using the static tool and temperature factor. The external air temperature changes the critical temperature factor and hence the threshold at which the risk of mould growth becomes apparent. The higher-than-normal internal surface resistance acts as a safety margin, producing a lower temperature factor which leads to an increased possibility of mould growth. The results from the static tool found no risk of mould growth, even with the additional safety margins.
Using the same indoor climate assumptions from ISO 13788:2012 in the dynamic tool WUFI 2D, the internal surface temperature was again calculated. The comparison of the results from WUFI 2D and THERM show a dynamic tool is required to produce usable results, as the static tool THERM and its assumptions do not provide a realistic assessment of the risk of mould growth. But a dynamic tool alone may not be adequate. The data the modeller inputs into the tool has a significant effect on the reliability of the results. The results from WUFI 2D, using internal conditions estimated using ISO 13777:2012 and calculated using WBS, are different. This is evident when the VTT Mould Growth Index is used to assess the risk, where the measured data and results using the internal hourly conditions from the WBS produce an VTT Index of $M = 3$, compared to the static indoor climate assumptions index of $M = 0$.

5. Conclusion

The findings from this study suggest the static tool (THERM) is unreliable compared to the dynamic tool (WUFI 2D) and measured data, even when additional safety margins are added. Due to the lack of useful outputs from the static tool, the temperature factor needs to be used. But this metric and the static tool do not account for the RH, which is one of the main drivers of mould growth on the internal surface.

Not only is a dynamic tool helpful to account for the temperature fluctuations of the changing external climate and the thermal inertia of the materials, but this highlights the importance of correct input data. Ideally the temperature does not drop below 20°C and the RH does not exceed 70%, but studies have found this is unrealistic for most New Zealand houses, especially for worst-case scenarios.

When using WUFI 2D with the internal conditions calculated with the WBS, the VTT index aligns closely to the measured data. But this method requires two simulations to be built in a WBS and BCS. The static tool THERM simulates results almost instantly, whereas the dynamic tool WUFI 2D can take upwards of 40 minutes. Furthermore, the WBS WUFI Plus used to obtain the internal conditions requires additional information of the building. Therefore, the question still remains whether a different tool can be identified that produces reliable results that align with the measured data but requires less time and experience from the modeller.

Acknowledgements

This research is funded by a Victoria University Doctoral Scholarship and a BRANZ Doctoral Scholarship.

References


